VOLUME VI NUMBER 1

BULLETIN

OF THE

AMERICAN ASSOCIATION

OF

PETROLEUM GEOLOGISTS

JANUARY—FEBRUARY, 1922

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

THE BULLETIN is the official publication of the Association, and it is to be published in six numbers with a subscription price of $5.00 per year. Extra postage on annual subscriptions is 30 cents for Canada and 53 cents for all other foreign countries to which postage is more than the local amount. Communications for the Editor and manuscripts should be addressed to R. C. Moore, Lawrence, Kansas. Remittances and business correspondence should be sent to C. E. Decker, Norman, Okla. Correspondence regarding advertisements should be addressed to R. C. Moore, Lawrence, Kansas.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

*Vol. I	$4.00	Vol. IV, Nos. 1, 2, and 3, each	$ 3.00
†Vol. II	4.00	Vol. V	10.00
†Vol. III	5.00	Vol. V, separate numbers, each	2.00
Vol. IV	7.50	Vol. VI	10.00
		Vol. VI, separate numbers each	2.00

*A few cloth bound copies of Volumes II and III are available at $1.00 additional.

†Only a few copies of Volumes I and II are still available.

Published by the American Association of Petroleum Geologists bimonthly, at Lawrence, Kansas. Entered as second class matter April 15, 1921 at the postoffice at Lawrence, Kansas under the Act of March 3, 1879. Claims for non-receipt of the preceding Numbers of the Bulletin must be sent to the Editor within three months of the date of the receipt of this number in order to be filled gratis.

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JANUARY—FEBRUARY, 1922

DIFFERENTIATION AND STRUCTURE OF THE GLENN FORMATION

By W. L. Goldston, Jr.

INTRODUCTION

The Glenn formation is the connecting exposure between the Pennsylvanian rocks in southeastern Oklahoma and sediments of the same age in north central Texas. The purpose of this paper is to describe the stratigraphy and structure of the Glenn and at the same time to offer a basis for correlating the Carboniferous deposits in southern Oklahoma with those of north central Texas. The economic importance of the Glenn formation is briefly pointed out.

A detailed survey of the Glenn formation was made during the summer of 1919. The writer was assisted in the field work by C. J. Wohlford, and by D. K. Greger, who made a collection and classification of the fauna of the Glenn. The author is also indebted to A. W. McCoy and Geo. E. Burton, under whose direction this work was conducted for the Empire Gas and Fuel Company and to Dr. L. C. Snider, for assistance and co-operation in the work. Especial appreciation is extended G. E. Moser and to the Drafting Department of the Oklahoma Geological Survey for maps and cross sections.

LOCATION

The Glenn formation is the name which has been given to the Pennsylvanian deposits in Oklahoma south of the Arbuckle

Mountains. The area of outcrop occurs in the southern two-thirds of Carter County and in a small portion of the north-central part of Love County. The area is irregular in shape covering approximately 175 square miles including a part of T. 2 S., R. 1 E.; T. 3 S., R. 1 W., and parts of Ts. 3, 4, 5, and 6 S., Rs. 1 and 2 E. Ardmore, the county seat of Carter County, is the principal town of this region.

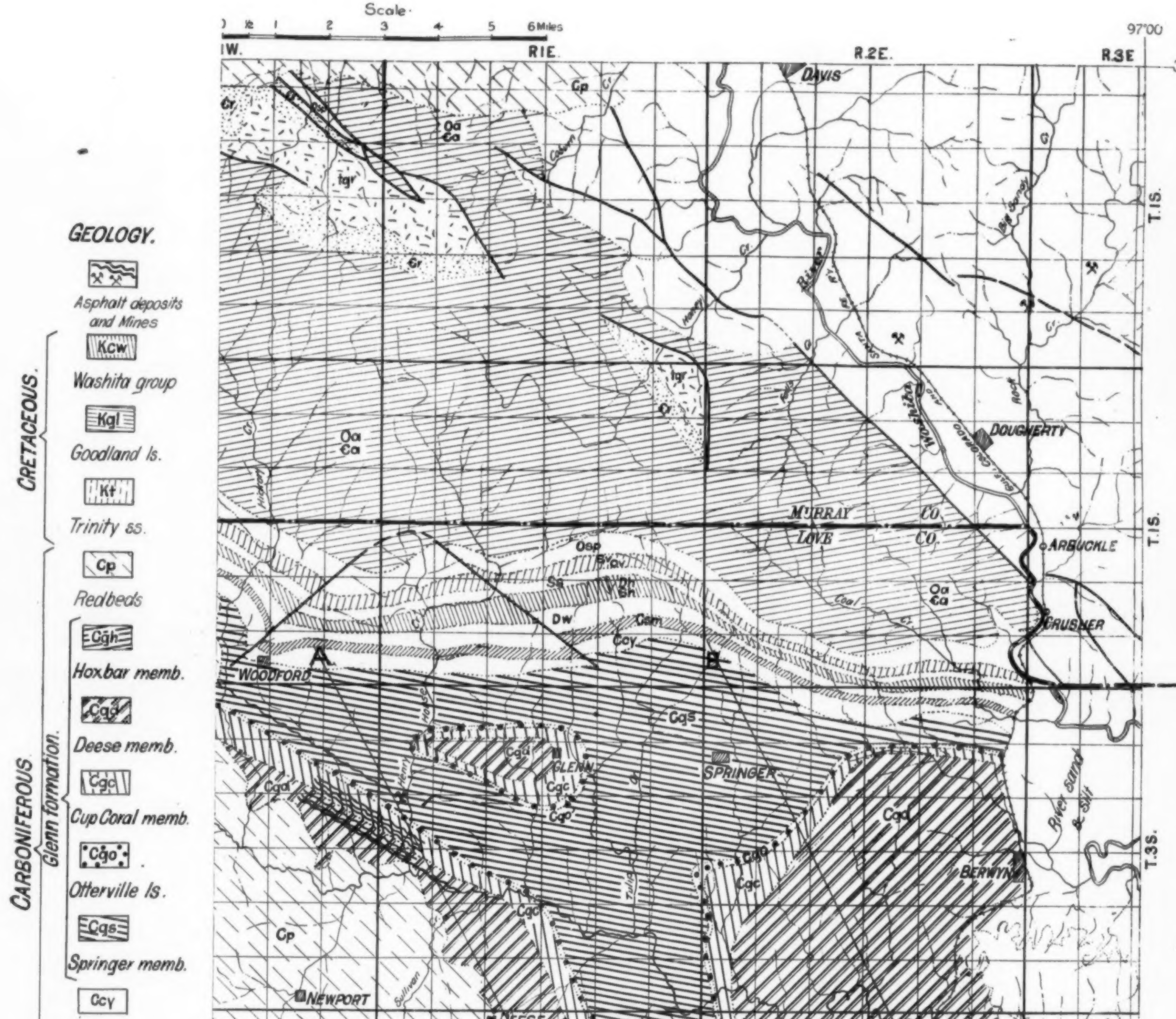
TOPOGRAPHY

The surface elevations in the area of Glenn outcrops range from 900 feet near the hills to 700 feet in the extreme eastern portion. The country lies in the Sandstone Hills region, in which the surface is made up of numerous sandstone and a few limestone ridges separated by broad shale valleys which trend in a northwest-southeast direction. Generally the drainage follows the shale valleys. The principal streams are Caddo and Hickory creeks. The stratigraphy and structure have had a marked influence on the topography of this area.

GEOLOGY

The areal geology of this region is shown in Plate I. The Glenn exposure lies essentially between two major uplifts; the Arbuckle Mountains on the north and the Criner Hills on the south. These uplifts are composed of rocks ranging in age from Pre-Cambrian to Mississipian, as follows: Tishomingo granite (Pre-Camb.), Reagan sandstone (Camb.), Arbuckle limestone (Camb.-Ord.), Simpson formation (Ord.), Viola limestone (Ord.), Hunton limestone (Sil.-Dev.), Woodford chert (Dev.-Miss.), and Sycamore limestone (Miss.). The Caney shales, representing the upper sediments of the Mississippian series are about 1,600 feet thick and where present form a valley about one-half mile wide at the base of these uplifts.

The Glenn formation lies directly above the Caney shales. The strata of the Glenn have been strongly folded. They consist of 15,000 to 19,000 feet of shales, sandstone, limestone, and conglomerates which stand practically on edge. On the east, south and southwest these rocks disappear beneath the Cretaceous sands of the Trinity formation. On the northwest



GEOLOGY.
Asphalt deposits and Mines
CRETACEOUS.
Kcw
Washita group
Kgl
Goodland ls.
Kt
Trinity ss.
CARBONIFEROUS.
Cp
Redbeds
Glenn formation.
Cgh
Hoxbar memb.
Cgd
Deese memb.
Cgc
Cup Coral memb.
Cgo
Otterville ls.
Cgs
Springer memb.
Ccy
Scale
6 Miles
97°00'
34°30'
R.1W.
R.1E.
R.2E.
R.3E.
T.1S.
T.3S.
DAVIS
DOUGHERTY
ARBUCKLE
CRUSHER
MURRAY CO.
LOVE CO.
WOODFORD
SPRINGER
GLENN
BERWYN
NEWPORT
DEESE
Washita
River Sand & Silt

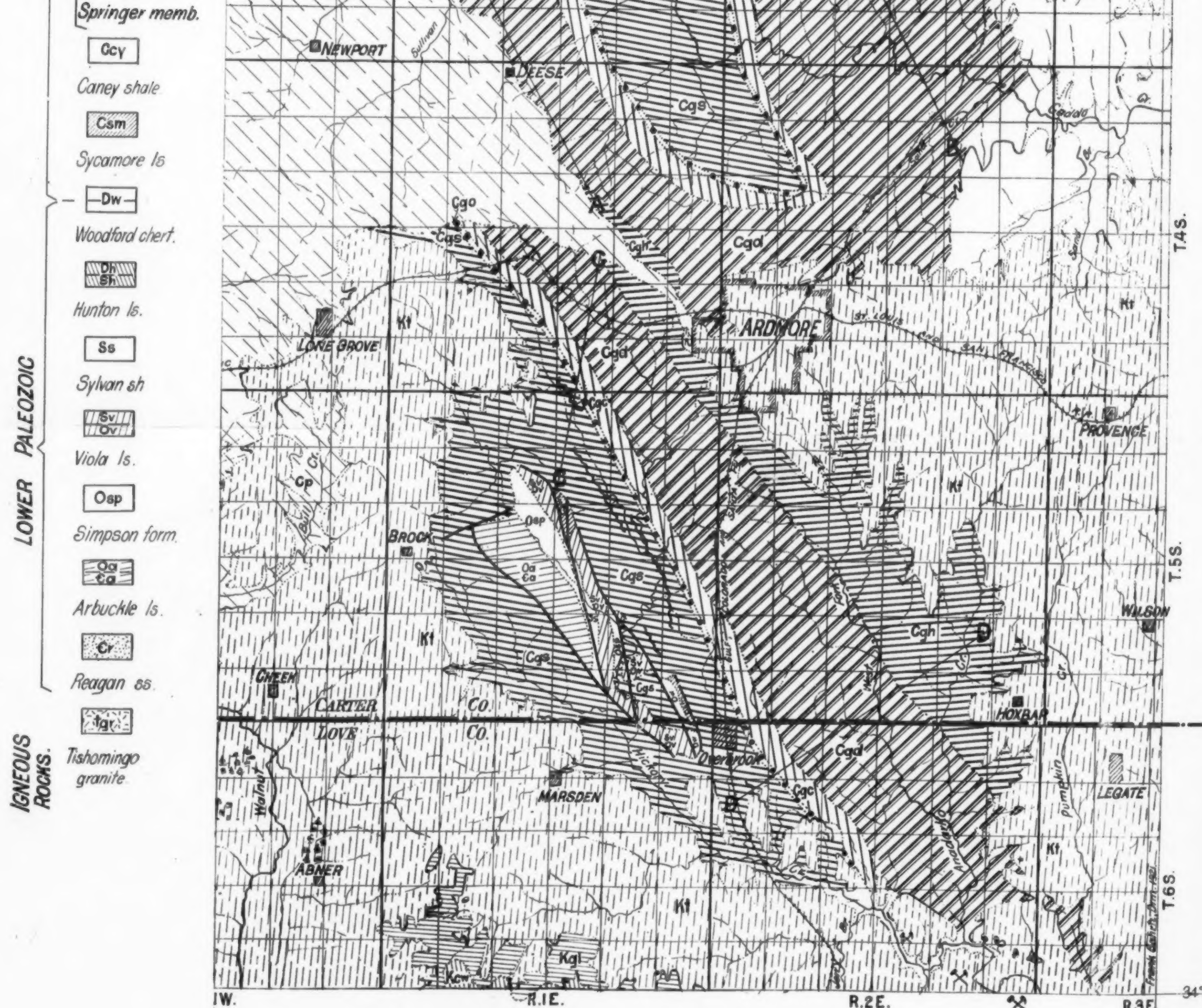


PLATE I. GEOLOGICAL MAP OF THE GLENN FORMATION IN THE ARDMORE BASIN

the overlapping deposits of Redbeds rest unconformably upon the up-turned edges of the Pennsylvanian strata.

STRATIGRAPHY

The Glenn formation apparently lies conformably upon the Caney shales; the two series having been separated largely upon the basis of lithology. The Caney shales are black, very hard, and slaty. The basal shales of the Glenn are black but much softer in character. A few Pennsylvanian cephalopods were found in the Santa Fe railroad cut north of Berwyn in a sandstone occurring about 400 feet above the base of the Glenn.

In Plate II are four vertical sections of the Glenn sediments. Section *A* totals 13,000 feet and was measured from the Arbuckle Mountains to the basin of the Ardmore Syncline. Section *C* was measured from the base of the syncline to the Criner Hills, and has a thickness of 12,000 feet. Toward the south and east, additional deposits form the upper part of the Glenn. The maximum thickness of these sediments is shown in section *D*. This section was measured southeast of the Criner Hills and has a thickness of 19,000 feet.

The Glenn has been divided into five members. Beginning with the basal member, these are here named the Springer, Otterville, Cup Coral, Deese, and Hoxbar members.

SPRINGER MEMBER

The Springer member includes the basal part of the Glenn formation, consisting of four to six thousand feet of sediments and covering practically one-half of the area included in the Pennsylvanian exposure. The outcrops of this member border the Arbuckle Mountains and project southward into a peninsular shaped area, the south end of which is three miles north of Ardmore. It also occurs around the Criner Hills covering a zone of about one and one-half miles in width.

The sediments of the Springer consists largely of black and blue shales separated by thin beds of sandstone and limestone. At the base, black is the characteristic color of the shales. Near the top, blue predominates, though even here, there are zones of black shales several feet thick. North of Ardmore,

this formation has no calcareous members. There are twelve brownish or drab sandstones ranging from a few feet to over one hundred feet in thickness. Some of these sandstones grade into shales toward the south and east. Around the Criner Hills, sandstones are less important and numerous beds of thin brownish limestones occur in these deposits.

South of Woodford and on the east side of the Criner Hills, asphalt deposits occur in the upper beds of this member.

OTTERVILLE LIMESTONE MEMBER

The Otterville limestone member forms a low ridge which runs southeast from Otterville. One mile east of the Ardmore Country Club, it runs northward and parallels the mountains again east of Springer. This member also surrounds the town of Glenn, extending as far west as Henry House Creek. South of Ardmore it runs southeastward paralleling the Springer member east of the Criner Hills.

The Otterville limestone is characterized by its oolitic texture. It consists of about 70 feet of solid brown limestone which grades locally into several beds of brown limestone separated by blue shales.

CUP CORAL MEMBER

The Cup Coral member parallels the Otterville limestone. It is composed of 1,500 to 1,800 feet of sediment which covers a zone ranging from one-third to three-fourths of a mile in width. These sediments consist of blue shales separated by thin sandstones and an occasional limestone. The member is easily distinguished by a white limestone near the top which carries a large cup coral, *Campophyllum torquium.* South of Ardmore this limestone is found exposed in only one place. In this area the top of the member is more easily distinguished by a thick conglomerate which forms the basal deposits of the Deese member.

South of Woodford, five of the seven sandstone beds of this member are asphalt bearing.

DEESE MEMBER

The Deese member lies in a northwest-southeast exposure just east of Deese. Its outcrops parallel those of other parts of the Glenn, and north of Ardmore they extend as far east as

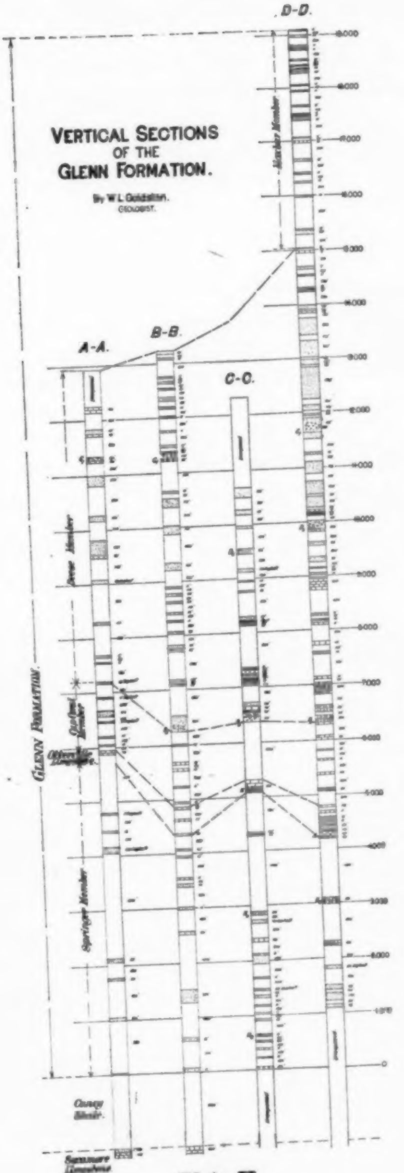

VERTICAL SECTIONS
OF THE
GLENN FORMATION.
A-A.
B-B.
C-C.
D-D.
GLENN FORMATION.
Dever Member
Springer Member
Caney Shale.

Plate II

the Santa Fe Railway. The basal part of this member is exposed in a small area immediately west of Glenn. It also occurs east of the Criner Hills, along a northwest-southeast zone which ranges in width from one and one-half miles, west of Ardmore, to three miles east of Overbrook.

This member produces the roughest topography in the region. Its sediments, with a total thickness of 6,000 to 8,000 feet, are characterized by a large number of massive sandstones, conglomerates, shales, and a few limestones. North of Ardmore the base of this member is marked by a brown limestone bearing an abundance of *Spirifer condor*[1]. South of Ardmore this (*Spirifer condor*) horizon is represented by a bed of chert.

HOXBAR MEMBER

The Hoxbar member lies southeast of Ardmore and west of Hoxbar. It is composed of 4,000 feet of the uppermost sediments in the Glenn formation. The basal sediments are characterized by several brown limestones, one of which is prolific *Fusilina cylindrica* horizon. The upper part of the member is characterized by white sandstones which are separated by light blue to yellow and red shales. This member becomes less calcareous toward the southeast. Limestones grade into shales and shales into sandstones and conglomerates.

Near the top of the member, four miles southeast of Ardmore, a coal seam, two to four feet thick, occurs in these sediments.

FAUNA OF THE GLENN FORMATION

Fossils are not abundant in the sediments of the Glenn. The Otterville limestone and Cup Coral members contain the most prolific horizons. Below is the list of the fossils collected and identified by D. K. Greger.

Springer Member

Erisocrinus typus	Pustula punctata
Rhombopora lepidodendroides	Goniatite sp.
Spirifer cameratus	Myalina subquadrata
Squamularia perplexa	Archaeocidaris magastylus
Composita argentea	

[1]MSS. species of D. K. Greger.

Otterville Limestone Member

Axophyllum rude
Michelinia eugeneae

Fenistella sp.
Rhombopora lepidodendroides

Hustedia mormoni
Productus cora
Productus semireticulatus
Productus punctatus
Composita argentea

Spirifer cameratus

Spirifer boonensis
Marginifera wabashensis
Spuamularia perplexa
Spiriferina kentuckiensis

Chaetetes milleporaceus
Leda bellistriata
Abundant unidentified gastropods, pelecypods, cephalopods.

Cup Coral Member

Campophyllum torquium
Axophyllum rude

Fenestella sp.

Composita argentea
Squamularia perplexa
Marginifera wabashensis
Spirifer boonensis
Spirifer cameratus
Productus semireticulatus
Productus costatus
Pustula symmetrica
Pustula punctata
Hustedia mormoni

Spiriferina kentuckiensis
Chonetes mesolobus

Chonetes granulifer
Productus semireticulatus
Meekospira peracuta
Ambocoelia planoconvexa
Hustedia mormoni
Dielasma bovidens

Nucula bellistriata
Nucula concentrica
Astartella concentrica

Bellerophon crassus
Platyceras sp.

Coloerus sp.
Orthotetes crassus
Euconospira turbiniformis

Deese Member

Rhombopora lepidodendroides
Stenopora carbonaria

Spirifer condor
Spirifer cameratus
Chonetes verneuilianus
Composita argentea
Productus semireticulatus
Productus cora

Pustula punctata
Spiriferina kentuckiensis
Squamularia perplexa
Marginifera wabashensis

Myalina subquadrata

Pleurophorus subcostatus

Hoxbar Member

Fusulina cylindrica

Productus semireticulatus
Productus cora

Composita argentea
Spirifer cameratus

Bellerophon sublaevis

CORRELATION

North of the Arbuckle Mountains all of the Pennsylvanian deposits below the Seminole conglomerates are correlated with the Glenn formation. This correlation is based upon the following structural relations. The so-called Franks conglomerate at Sulphur rests unconformably upon the upturned edges of the older rock. Folding in the latter rocks conform to that in the Glenn formation. The conglomerate at Sulphur represents the deposits from a sea which came after Glenn times. According to work by E. A. Beauman, this conglomerate and the Seminole conglomerate, are the same formation. At the base of the Seminole conglomerate the angular unconfermity is an evidence that the period of mountain building movement, which affected the position of the Glenn sediments, also affected the position of the sediments immediately below the Seminole. These sediments are not so strongly folded as those of the Glenn, but the unconformity at the base of the Seminole is pronounced and is known to exist as far north as Okfuskee County.

In north-central Texas the Bend, Millsap, and Canyon formations are the probable equivalents of the Glenn sediments. At the beginning of Cisco times, the members of the Canyon formation were overlain with a group of coarse sediments occurring in the basal part of the Cisco formation. A corresponding change in sedimentation is found immediately above the Glenn.

According to V. V. Waite of the Atlantic Petroleum Company, a fossil representing Cisco times, was found in a well in the Loco field. As the producing sand in the Loco field rests unconformably upon the Arbuckle limestone, these sediments are post-Glenn.

Charles Schuchert, while visiting this area, was inclined to place the fossil bearing sandstone near the base of the Springer member as the equivalent of the Wapanucka limestone. Based on this and the evidence furnished by V. V. Waite and correlating the conglomerate occurring at the base of the Deese member with those in the Thurman sandstone, the following tentative correlation table is presented.

CORRELATION TABLE

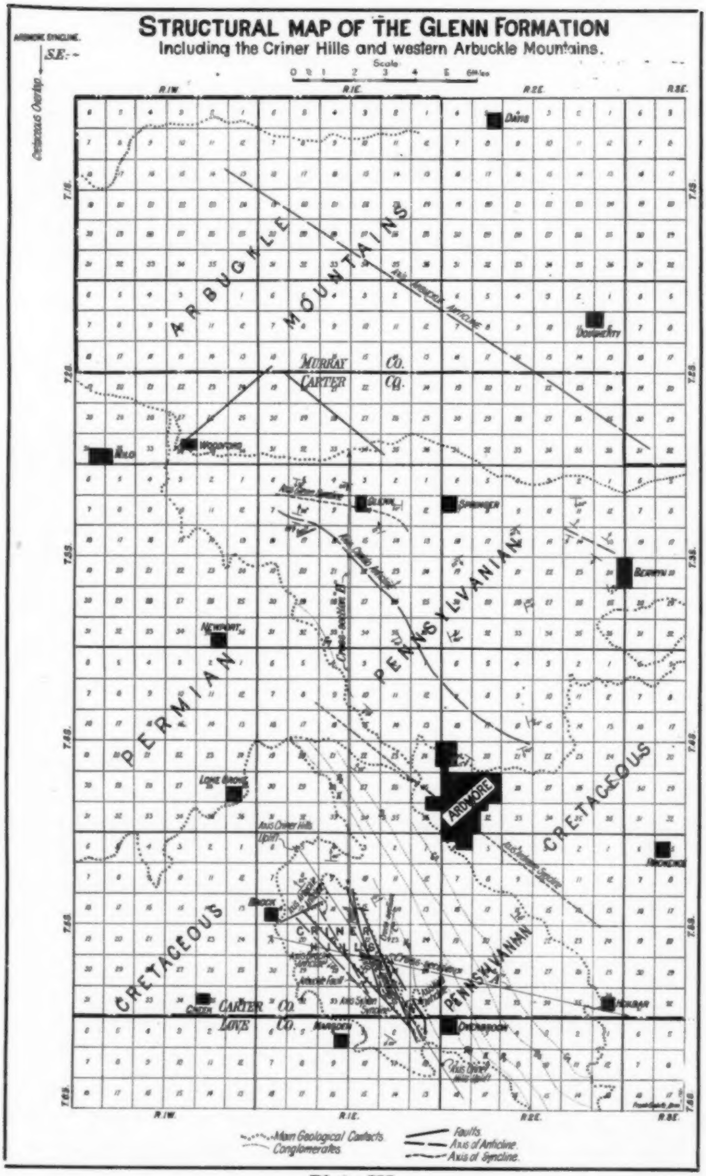
North Central Texas	Oklahoma South of Arbuckle Mtns.	Oklahoma North of Arbuckle Mtns.
Canyon formation	GLENN FORMATION Hoxbar member	Holdenville shale Wewoka formation Wetumka shale Calvin sandstone
Strawn formation	Deese member	Sonora formation Stuart shale Thurman sandstone
Millsap formation	Cup Coral member Otterville limestone	Boggy shale Savanna sandstone McAlester shale
Smithwick shales Marble Falls limestone	Springer member	Hartshorne sandst'ne Atoka formation Wapanucka limest'ne
Lower Bend shale	Caney shales	Caney shale

CONFORMITY OF THE GLENN WITH THE OLDER ROCK

It has generally been thought that an angular unconformity exists at the base of the Glenn formation. This conception is probably in part due to the following statements by J. A. Taff*:

The Carboniferous rock as on the northeast side of this anticline has suffered folding, and near the contact with the older rocks are generally steeply inclined and dip toward the northeast. East of the Hickory Creek dips of Carboniferous rocks at and near the contact vary from 25 degrees to 40 degrees, while the older rocks dip at greater angles and in places in different or opposite directions, indicating a great unconformity. Immediately east of the road at its crossing of Hickory Creek, near the west side of sec. 35, T. 5 S., R. 2 E., the contact is evidently upon a fault. At this place the Simpson formation dips toward the southeast while the dip of the Carboniferous is 40 degrees in the oppo-

*Prof. Paper, U. S. Geological Survey, No. 31, 1904, pp. 50.



STRUCTURAL MAP OF THE GLENN FORMATION
Including the Criner Hills and western Arbuckle Mountains.
ARBUCKLE MOUNTAINS
MURRAY CO.
CARTER CO.
PERMIAN
PENNSYLVANIAN
CRETACEOUS
CRINER
ARDMORE
LOVE CO.
Main Geological Contacts
Conglomerates
Faults
Axis of Anticline
Axis of Syncline

Plate III

site direction. Farther southeast and in the opposite side of the axis of the fold, the Viola, Sylvan, and Hunton formations dip northeast, in the same direction as, but at higher angles, than do the overlying Carboniferous strata. West of Hickory Creek, at the base of the Coal Measures deposits, is a strong unconformity which is probably in part due to faulting. The beds near the base are variable in character along this contact. In some places they appear to be chiefly shale, while in others, especially in secs. 22 and 27, are coarse limestone conglomerates consisting of pebbles of the same nature as the limestones of the Criner Hills.

The occurrence in the Glenn sediment of limestone pebbles of a similar nature to the rocks of the Criner Hills and Arbuckle Mountains is no proof of an angular unconformity at the base of the Glenn. During Glenn times, land masses, composed of similar material from which these pebbles may have come existed east of this area. The Sabine Uplift and Ouachita Mountains are evidences of such uplifts.

In each locality mentioned by Taff, the apparent unconformity between the Coal Measures and older rocks may be due entirely to faulting. The Criner Hills are so intensely faulted that it is almost impossible to determine the true relation between the Glenn formation and the older sediments in this area. The south side of the Arbuckle Mountains offers a much better opportunity for studying this relation. In this region the strike of the basal beds of the Springer member parallels the strike of the Caney shales and Sycamore limestones. The dip of the younger rocks is in the same direction as that of the older. With few exceptions the angle of dip in the basal sediments of the Glenn are equal to and in most places is greater than that in the Mississippian deposits. But since an actual exposure of the Glenn in contact with the Caney shales was not found, no proof of a conformity or an unconformity can be given. The observations as near the contact as exposures were found in this area however, lead the writer to conclude that the Glenn rests conformably upon the Caney shales.

STRUCTURE

In Plate III is a structural map with cross sections of this area. The region is characterized by five steep folds: the Criner Hill Uplift, the Ardmore Syncline, the Caddo Anticline,

the Glenn Syncline, and the Berwyn Anticline. With the exception of the area west of the Criner Hills these folds become less intense toward the south and east. The dip of the rock varies from 90 degrees near Woodford to 5 degrees at Berwyn, and from 65 degrees on the east side of the Criner Hills to 20 degrees west of Hoxbar. West of the Criner Hills, the dip flattens toward the west.

CRINER HILLS UPLIFT

The Criner Hills Uplift is located about 5 miles southwest of Ardmore. The structure of the Glenn sediments around the uplift can be best understood by first pointing out briefly the principal structural features of the older rocks.

The Criner Hills consist of a number of parallel northwest-southeast ridges separated by narrow valleys. Arbuckle limestone, Viola limestone, Hunton limestone, and Sycamore limestone form the ridges. Simpson formation, Sylvan shale, and Woodford chert form the valleys.

Structurally the Criner Hills consist of remnants of three folds. The Arbuckle anticline forms the northwestern portion. The Viola anticline includes the southeastern part and the Sylvan syncline forms the central and southwestern part of the hills. The uplift is bounded on the west by a fault. This fault obliterates the south limb of the Arbuckle anticline and has a throw of sufficient displacement to bring the basal sediments of the Glenn formation in contact with the Arbuckle limestone. On Hickory Creek this fault is intersected by the Sylvan fault which runs northeastward across the Sylvan syncline. The Viola anticline is cut by the Simpson fault which almost parallels the axis of this fold. A fourth fault, exists on the east exposure of the Viola limestone. With the exception of two small areas these three faults limit the hills on the east.

The sediments of the Glenn surround this intensely folded and faulted area of pre-Pennsylvanian rock. On the north and west sides the basal part of the Springer is exposed. On the east side the whole section from Springer to Hoxbar members are exposed. These sediments assume the shape of an anticlinorium which has been intensely faulted on the west

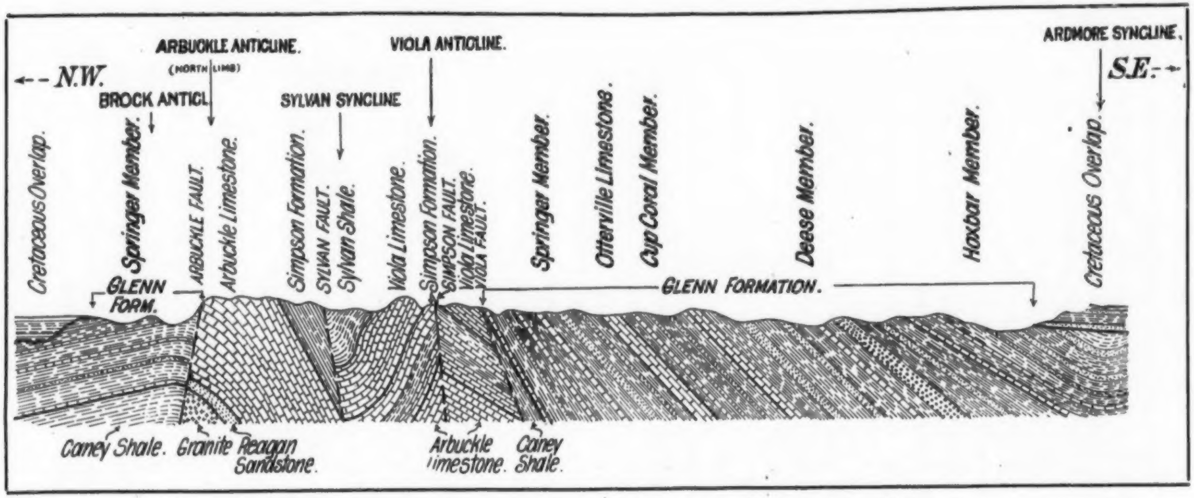


Plate IV. Cross-section A. N.W. S.E. The Criner Hills and the Glenn Formation surrounding these Hills.

side and overturned in places on the east side. This anticlinorium is made up of three principal parts, the Brock anticline on the west, overturned folds on the east, and the central or major fold. The major fold rises in sec. 5, T. 5 S., R. 1 E., and extends southeastward about the axis of the hill. The south limit is buried beneath the Cretaceous overlap and is undefined. On the east side the dip of the rock varies from 55 to 70 degrees; on the north side from 25 to 50 degrees; on the west side from 10 to 20 degrees. The rocks generally are infolded with the older sediments. With the exception of faulted areas and on overturned folds, they dip in the same direction but not always at the same angle.

The Brock anticline parallels the Criner Hills. Its axis crosses secs. 17, 20, 21, 28, and 34, T. 5 S., R. 1 E. The Arbuckle fault which limits the Criner Hills on the west, cuts the northeast flank of this fold about one-half mile east of its crest. There are also a number of cross faults cutting this fold. The exact location and courses of these faults were not determined. The sediments forming the Brock anticline belong to the lower part of the Springer member. On the east side the rock dips at an angle of about 25 degrees, on the west side from 20 to 15 degrees, flattening towards the west.

On the east side of the Criner Hills Uplift are several overturned folds. In the southwest quarter of sec. 36, T. 5 S., R. 2 E., and the northeast quarter of sec. 1, T. 6 S., R. 2 E., the basal part of the Glenn is overturned. The best example of this kind of folding is found in the southwest quarter of sec. 14, T. 5 S., R. 1 E. A cross section of this fold is given. (Figure 1).

ARDMORE SYNCLINE

The Ardmore syncline lies between the Criner Hills and the Caddo anticline. Permian and Cretaceous sediments fill the bottom of this basin. The approximate location of its axis extends through Ardmore crossing secs. 8,16, 22, 23, and 36, T. 4 S., R. 1 E.; sec. 31, T. 4 S., R. 2 E., and secs. 5, 9, 10, and 14, T. 5 S., R. 2 E. The sediments exposed on the side belong to the Deese and Hoxbar members. The northwest end of the basin is narrow and steep, the rock dipping 55 degrees and 70 degrees on the north and south sides respectively. The trough

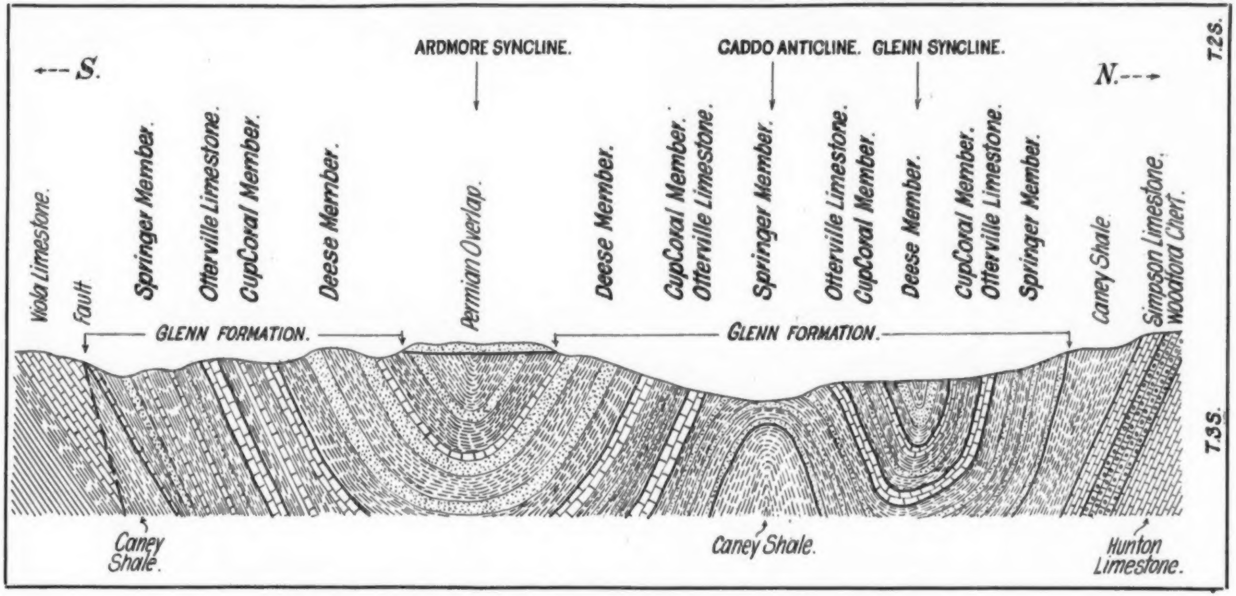


Plate V. Cross-section B. N-S. The Glenn Formation between the Criner Hills and the Arbuckle Mountains

broadens toward the south, the dip having flattened to 20 degrees on the south side.

CADDO ANTICLINE

The Caddo anticline is 12 miles long and is the largest fold in the Glenn formation. Its axis generally parallels both the Arbuckle Mountains and the Criner Hills. Rising on Henry House Creek in the eastern part of sec. 7, T. 3 S., R. 1 E., it extends southeastward across secs. 8, 16, 22, 35, and 36, T. 3 S., R. 1 E.; sec. 1, T. 4 S., R. 1 E.; and secs. 7, 17, 21, and 22, T. 4 S., R. 2 E. With the exception of the Hoxbar member and the basal part of the Springer, the whole Pennsylvanian sections are exposed along the flanks of the fold. The Springer and the Otterville limestone outcrops occur along the axis. The rocks dip from 90 degrees on the extreme north to 45 degrees on the south end.

GLENN SYNCLINE

The Glenn syncline lies between the Caddo anticline and the Arbuckle Mountains. Rising on Henry House Creek in the northeast corner of sec. 7, T. 3 S., R. 1 E., it extends southeastward across secs. 8, 9, 10, 11, 14, 13, T. 3 S., R. 1 E. The sediments forming this basin belong to the Otterville limestone, Cup Coral, and basal part of the Deese members. The rock dips from 90 degrees on the west end to 30 degrees east of Glenn.

BERWYN ANTICLINE

The Berwyn anticline is a narrow and steep fold located northwest of Berwyn. This fold affects only a few hundred feet of the sediments in the Deese member. The axis of this fold was not accurately located. Its approximate location is given on the map in Plate III.

ASPHALT DEPOSITS

There are numerous and extensive deposits of asphalt in the sediments of the Glenn formation. These deposits occur in three zones. South of Woodford, there are nine sandstones bearing asphalt. This zone is about 6 miles wide. The asphalt deposits are found in secs. 2, 3, 11, 12, and 13, T. 3 S., R. 1 W., secs. 18, 19, and 20, T. 3 S., R. 1 E. The sandstones are continuous but do not carry asphalt south of Caddo Creek.

The second zone of asphalt deposits occurs on the east side of Criner Hills. In this area are four asphalt bearing sandstones. These deposits are found in sec. 34, T. 4 S., R. 1 E., secs. 3, 4, 10, 14, 15, 23, 24, 25, and 26, T. 5 S., R. 1 E., and in sec. 7, T. 6 S., R. 2 E. There is also a deposit in sec. 21, T. 4 S., R. 1 E.

The third zone occurs in the horizontal sands of the Trinity formation, and is found in secs. 26, 27, and 35, T. 6 S., R. 2 E., and in secs. 1 and 2, T. 7 S., R. 2 E. The Glenn sediments, standing at an angle of about 65 degrees, underlie the Trinity sands and are the source of asphalt found in this area.

With the exception of the deposit in sec. 21, T. 4 S., R. 1 E., the three zones of asphalt are found at approximately the same relative stratigraphic position. The asphalt horizon of the Glenn formation includes the upper part of the Springer member, the Otterville limestone member, the Cup Coral member, and the basal part of the Deese member.

OIL AND GAS POSSIBILITIES

The Glenn sediments where exposed on the surface, are for the most part too strongly folded to permit an accumulation of oil and gas. There are only two areas where the dip of the rock are at angles low enough to furnish the physical conditions required for capping oil or gas. These are the Brock anticline on the west side of Criner Hills and an area including parts of secs. 11, 12, 13, and 14, T. 3 S., R. 1 E.

The Brock anticline is described under structure. The sediments forming this fold are stratigraphically below any of the asphalt sands found in the Glenn formations. The dip of the rock varies from 10 to 20 degrees and are not much stronger than the dip found in the lower producing sands of the Hewitt field. Since the sediment forming the Brock anticline is stratigraphically below the asphalt horizon of the Glenn formation, occurrence of oil or gas in these sediments is considered doubtful.*

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*Editor's Note: The Crinerville well of the Amerada Petroleum Company located by Sidney Powers on this anticline is reported to flow 60 bbls. of oil at 1312 feet.

The structure of the area in secs. 11, 12, 13, and 14, T. 3 S., R. 1 E., consists of a broad nose plunging towards the south. This nose is formed by southeast dips in secs. 7, 8, and 18, T. 3 S., R. 2 E., and by southwest dips in sec. 13 and the northern part of sec. 14, and by west dips in the western part of

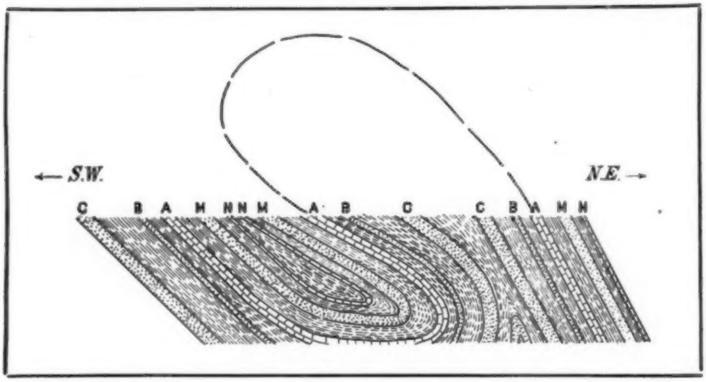

Figure I. Cross-section C. N. E.-S. W. Overturned Fold in Springer Member of the Glenn Formation East of Criner Hills. Secs. 14 & 23 T. 5S., R. 1 E.

sec. 11, T. 3 S., R. 1 E. The dips vary from 10 to 30 degrees. The most prominent asphalt sand south of Woodford underlies this area at about a depth of 2,000 to 2,200 feet. This sandstone barren of asphalt is exposed on Caddo Creek in sec. 25, T. 3 S., R. 1 E., dipping northeast of Caddo anticline at an angle of 45 degrees. It comes to the surface again in sec. 1, T. 3 S., R. 1 E., dipping away from the mountains at an angle of 30 degrees.

South of the Arbuckle and Wichita Mountains the Glenn formation is very probably present over the greater portion of southern Oklahoma. Where not too strongly folded this formation may be considered an important source of oil and gas in this part of the State. The Hewitt field is an example of production from the Glenn sediments. The producing sands of the Hewitt field are very likely the equivalents of some of the asphalt sand exposed in the Glenn formation. On the Hewitt fold the upper sediments of the Glenn were removed by ero-

sion which occurred just prior to the invasion of the Redbed seas. Similar conditions would bring the asphalt horizon of the Glenn formation within reach of the drill in othehr places in southern Okiahoma.

With the exception of a few wells in the Healdton field, the Healdton, Wheeler, Loco, Robberson, and probably the Fox field, are most likely producing from sands which are post-Glenn. But even in these fields it is not unlikely that the Glenn is the original source of some of the production found in the younger sediments.

OIL GEOLOGY OF WARREN COUNTY, KENTUCKY

By Stuart St. Clair*

INTRODUCTION

Prior to 1919 there were no producing oil wells in Warren County although there was considerable production in Allen County, the adjoining county on the east. Naturally, oil development should start on the east side of the county and it was in the spring of 1919 that the Moulder pool was opened. Gusher wells were brought in from the top of the Devonian limestone immediately underlying the black shale and at depths of little more than 400 feet. Other areas of small wells were opened in the eastern part of the county in the same year and also the Sledge pool, another gusher section. On November 3, 1919, the discovery well on the Davenport farm, four miles northwest of Bowling Green, was completed, and the real development of Warren County dates from this time although it was the spring and early summer of 1920 before the drilling campaign was in full swing. To add to the boom incident to the discovery of oil in the Bowling Green district in the limestone underlying the Devonian black shale, gusher wells were found in a stray sand in the St. Louis limestone at depths of about 450 feet.

TOPOGRAPHY

Warren County may be divided into two topographic provinces, the larger being the plateau area which extends from the eastern side of the county westward to the escarpment ridge, about four miles west of Bowling Green. The plateau is developed on the St. Louis and Ste. Genevieve limestones and is a rolling country deeply incised by the two main streams. Barren River which crosses the central part of the county in a general northwestward flow, and Drakes Creek, its principal tributary, which flows north through the east central part of the county. The drainage of most of the remaining area

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of the plateau is underground and the surface is marked by many sink-holes. The second topographic province is the highland area which occupies the northwestern part of the county and covers about one-third the area that the plateau country does. The highland area is developed chiefly on the Gasper limestone and the Cypress sandstone and is from 200 to 250 feet above the plateau. It is deeply dissected by the drainage, Green River, Barren River, and Gasper River.

GEOLOGY

The geology of Warren County which we must consider extends from the Niagaran limestone of Silurian age to the Cypress sandstone of the Chester, although the surficial geology is confined between the upper ledges of the Fort Payne of lower Mississippian age and the lower beds of the Pennsylvanian or Coal Measures.

Some deep tests for oil have penetrated the Ordovician limestone for probably as much as 600 feet or more in search of an equivalent of the Trenton oil formation. The well logs show prevailing limestones in the Ordovician and some oil is reported in the upper 100 feet of the series. The overlying Silurian, most of which is probably Niagaran, is made up chiefly of limestone with some shale. Some of the limestone beds are soft and earthy, and some are coarsely crystalline in texture. The thickness of the Silurian is between 80 and 100 feet. Overlying this is about 50 to 55 feet of Devonian limestone, light gray to brown in color, and referable to the "Corniferous," (Onandaga), the upper beds of which are the oil sands of northern Allen and eastern Warren counties. At the outcrop in Allen County the Devonian limestone is only a few feet thick, but in going westward the formation thickens materially. Most of the oil in the western half of Warren County is found at depths ranging from 68 to 135 feet below the Black Shale and, therefore, comes from rocks of Silurian age.

The Devonian black shale, which is the key-rock for subsurface work, is about 50 feet thick in the eastern part of the county but thickens to about 100 feet in the western part, with an average in the oil belt west of Bowling Green between

75 and 90 feet. The variation in thickness over short distances is due to an uncomformity with the overlying Mississippian and, therefore, structural work should preferably be based on the lower contact of the shale.

The basal Mississippian formation in Warren County is the New Providence shale which may be as much as 30 or 40 feet thick in the eastern part. High grade oil of an amber color is found in an horizon at or near the top and probably an equivalent of the Beaver sand of Wayne County. Overlying the New Providence is the Fort Payne, the upper ledges of which are exposed along Barren River in the extreme eastern part of the county. These ledges are chiefly chert but in unweathered or primary condition the formation is a siliceous limestone. The Fort Payne with the overlying Warsaw formation, which is chiefly fossiliferous limestone with some shale, the latter at the top, are about 220 feet thick in eastern Warren County, but they, (probably largely the Fort Payne), thicken in going westward, for in the deep pool area west of Bowling Green there is an interval of 330 to 340 feet from what is probably the basal part of the St. Louis to the top of the Black Shale. This would include the New Providence, if present.

The St. Louis limestone is the next younger formation and may be unconformable with the underlying Warsaw, a relation that is suggested by the absence of the Spergen limestone and cross-bedding and coarse-grained layers in the basal part of the formation. The St. Louis is a dense blue to gray limestone, very siliceous in many horizons as weathering produces large quantities of chert. The formation can be recognized by the coral *Lithostrotion basaltiforme* which is scattered over the surface as chert pieces. The shallow gusher wells in the western half of Warren County come from the lower or even basal limestone beds of the St. Louis. The thickness of the formation is from 335 to 350 feet.

The Ste. Genevieve, including the Fredonia member at the base, and the Gasper may be considered together for lithologically they are hard to separate as both are light colored limestones, and both are oolitic. The general absence of chert and *Lithostrotion basaltiforme* distinguishes them from the St.

Louis. The absence in Warren County of the O'Hara member of the Ste. Genevieve and the Bethel sandstone, which appear in Todd County to the southwest, may or may not denote a stratigraphic break at the base of the Gasper. The thickness of the Gasper and Ste. Genevieve is between 390 and 400 feet.

The Cypress sandstone overlies the Gasper and there is probably an unconformity between the two as the interval between the base of the Cypress and the top of the black shale in wells not far apart varies considerably. It must be borne in mind, however, that there are other breaks in the stratigraphic column which might account for these differences. The average interval is about 1085 feet.

In the northwestern corner of the county a few thin Chester formations above the Cypress come in, above which lies unconformably the Pennsylvanian sandstone and conglomerate.

STRUCTURE

The general structure of Warren County is a northwestward dipping monocline, the average dip being 30 to 40 feet to the mile. This regularity is broken by several uplift areas which extend in a general direction normal to the monoclinal dip. There is an uplift extending northeast-southwest along part of the eastern side of the county for along Bays Fork and Barren River there is a series of domes, the domes occupying many of the bends in the streams mentioned. Drakes Creek follows another line of uplift as many of the bends are structural. West of Bowling Green is probably the most discernible series of folds in the county, the uplift paralleling the escarpment ridge. Smaller paralleling folds lie a little southeast of the major fold. On the western side of the county Gasper River in part follows an uplift for well-defined domes occupy many of the river bends. Between the escarpment ridge to the east and Gasper River, the area has a very uniform monoclinal dip which is broken by terracing in a few localities. An interesting feature in the geology is the relation of the structure to the main drainage and to the topography in the western part of the county. Nearly all the prominent bends in Barren River and its three main tributaries are structural. The domes and

terraces in the highland area are strongly reflected in the topography.

OCCURRENCE OF THE OIL

Oil has been found at eight or nine different horizons in the geologic section that has been drilled through in Warren County, six having proven commercial. For brevity the six may be grouped into four so as to make formational units. These oil sands are the basal St. Louis in which the gusher wells in the Bowling Green area are found; the Beaver sand which occurs in the New Providence in the eastern part of the county and from which the amber oil is produced; the Devonian lime sand with its two pays; and the Niagaran lime sand.

St. Louis sand. The gusher wells in the Bowling Green district come from a sand at or near the base of the St. Louis limestone, probably in the lower 20 or 30 feet. The sand is a dark granular and well crystallized limestone. When drilled up it looks like dark carbonaceous sand but when larger fragments are bailed out it is seen to be crystalline and to contain many fragmentary fossil shells and is soft enough to be crushed between the fingers. Most of it will dissolve in acid and any residue is chiefly amorphous silica. This dark limestone may have a considerable thickness in some localities and intercalated with it are thin black to brown shale lenses. In the eastern pools of the county the interval between the basal St. Louis and the top of the Devonian black shale is about 250 feet; in the pools south of Bowling Green the interval is about 325 to 335 feet; in the pools several miles west of Bowling Green the interval is between 340 and 350 feet. This shows a thickening of the Mississippian formations below the St. Louis in going northwest, down dip, toward the Central Coal Basin of Western Kentucky.

The basal St. Louis oil sand is not persistent laterally for offsets to good wells may not find any oil and in many cases no water either. The writer suggests, therefore, that the basal beds where productive may occupy shallow erosional depressions in the underlying formation, or sink holes, which may have formed in the soluble Warsaw limestone during the inter-formational epoch, and that the black shale lenses may be

confined to areas where these depressions existed at the time of basal St. Louis deposition. Satisfactory records are not available nor was the writer able to examine the cuttings from enough wells to verify the presence or absence of these thin shale beds in wells which produced or did not produce oil from this sand. The presence of soft carbonaceous limestone, and in many wells studied carbonaceous black shale, coarsely crystalline limestone, abundant fossil fragments, water-worn chert fragments, and irregularity in a real distribution of the oil horizon, suggest basal sedimentation.

The St. Louis sand contains gas, oil, and salt water all of which are under great pressure in the big producing wells. The pressure is soon relieved, however, and the decline in production is very rapid, especially after several wells are drilled in the same locality. Wells that have flowed between 1000 and 2000 barrels the first day may be exhausted within a few weeks or at best a few months. There are exceptions, however, for a few are still producing as much as 50 barrels per day after three or four months pumping. Also a number are doing from 10 to 20 barrels after several months whose initial production was from 100 to 500 barrels. Some wells have come in flowing salt water, others have pumped salt water for a few hours or days and come on to oil. Each pool or unit in a pool has just so much fluid in it, evidently, and a well pumping salt water from a location down the dip from a producing well may draw the oil from the producing well, the former changing from water to oil. Shooting a well may ruin an offsetting producer, and in other cases dry holes may be drilled surrounding a producer. These facts show the spotted distribution of the St. Louis oil sand.

The oil and gas are probably indigenous to the basal beds of the St. Louis and come from the carbonaceous shale and the organisms, the fossil remains of which we now find in the limestone. The salt water is fossil sea water and is confined to the depression areas in which the basal oil horizon was deposited. The oil and gas have not migrated far from the point of origin and have arranged themselves, as far as pent up gas pressure would allow, according to their respective specific gravities in the small pools or units of a larger pool. The ac-

cumulation is only indirectly controlled by the structure of the rocks as the determining factor is the presence or absence of the basal oil horizon and this is dependent upon the sedimentary conditions that obtained at the beginning of St. Louis time. Where the basal oil horizon underlies a considerable area, structure has an influence on the accumulation and pools may coincide with the top of a dome or its flank. However, on many of the most pronounced structures in Warren County the basal St. Louis oil sand is absent.

Beaver sand. The Beaver sand is productive only in the eastern part of the county and is found at the top of the New Providence formation. The oil is very high grade and amber in color and is probably a product from the organic matter which was deposited with the underlying green colored shales. Accumulation is dependent entirely upon the presence or absence of the sand, which is lenticular, and secondarily upon the structure. Some of the wells come in at 100 barrels or better, but they soon decline to small production. Only a few wells are producing from this sand at the present time.

Devonian ("Corniferous") sand. The Devonian lime sand which underlies the black shale is productive principally in the eastern part of the county. There are two pays in the pools of this section and both are thought to be in the Devonian although the lower may be in the upper beds of the Silurian limestone. The first pay is the important producer and lies from a few feet to about ten feet below the base of the black shale, and is from five to ten feet thick. At the present time all the wells in this sand have small production, although the first wells in the Moulder and Sledge pools blew in at from 100 to 1000 barrels. The Moulder wells declined rapidly but the first few wells in the Sledge pool, by pinching them in, held up for some months and produced a great quantity of oil. The pay sand in these pools is brown in color and very porous, and the oil is under both gas and salt water pressure, but as the pressure is now relieved the wells are nearly exhausted.

In the field west of Bowling Green the Devonian produces very little oil, in fact the writer knows of only one commercial well, which is producing from a ten foot pay 36 feet below the

base of the black shale, although showings are reported at this horizon in many wells.

Silurian (Niagaran) sands. The Niagaran sands are the present big producers in Warren County and they lie from 68 to 130 feet below the black shale. The color of the pay sand is light or dark gray and the rock is soft and either earthy in appearance or crystalline, and contains very little grit.

The Niagaran limestone is apparently non-productive over the larger part of Warren County as oil in commercial quantities is found in it only within a restricted area in the west central part. Taking the western edge of Bowling Green as the apex, the producing area extends out fan-shaped covering an arc of about 125 degrees. The limit of the fan is but a short distance beyond the escarpment ridge, approximately four miles from the apex, but it may be extended a little farther. Within this fan area of production there are a number of non-productive sections where either the rock structure is too low or the sand condition is poor. Most of the producing wells are located on the tops and along the flanks of the anticlines and domes. In the saddles and in the synclines the sand conditions are generally poor, and little if any oil is found and rarely salt water to amount to anything.

The most pronounced line of structure, which is a series of domes, and upon which some of the best wells in the district are located, extends along the base of the escarpment ridge. The Niagaran sand is uniformly porous under this anticline which includes the Briggs dome, the Morris dome, the Scott dome, the Davenport dome, and across the river the domes in Winlock Bend of Barren River. Distinct saddles separate each of these domes. Paralleling this main anticline and lying to the east of it are other anticlines. The Davenport dome, which has a closure of 40 feet, is typical. The surface elevation near the river, Davenport lease, well No. 15 is 444 feet above sea-level, the depth to the top of the sand is 960 feet, bottom 967, and the base of the oil, therefore, 523 feet below sea-level. The pay is from 6 to 20 feet thick in this section and very little salt water is found in the oil formation. This water is under no pressure and is not bottom water but occurs directly in the

pay. Adjoining wells may show no water at all. This feature will be discussed under origin.

The top of the Niagaran sand in the wells west of Bowling Green is between 68 and 115 feet below the base of the black shale, and the pay streaks may vary in short lateral distances between these limits. The depths of the wells in the eastern part of the producing area west of Bowling Green are about 900 feet; in the western part, near the river where the surface elevation is about 450 feet, the depth is about 950 feet. Conforming to the topography the wells increase in depth and on the escarpment ridge the wells are 1300 feet and more.

Salt water was encountered in a few wells in the producing territory but the amount is negligible and it may not be found in offset wells. Outside the producing area a very few wells have struck salt water, but there are enough tests which encountered no salt water to indicate that there is no quantity or pressure of salt water behind the oil in the western part of Warren County.

SOURCE OF THE OIL

The source of the oil in the Devonian and the Silurian sands will only be discussed briefly. There seems to be but two premises, the oil is either indigenous to the limestones and probably to the sand horizons themselves, or the oil has migrated from the overlying Devonian black shales to the porous sand horizons below. The presence of a porous bed in the limestone is the all important factor in the accumulation of the oil although other factors may offset the presence of this requisite. Therefore, drilling may disclose a porous bed in the limestone which may or may not contain oil. On the other hand wells may be drilled on good structures and no oil or salt water found because the rock is tight, although fossils, which are evidence of pre-existent organic life, are found in what should be the oil pay, or adjacent to it. Again, wells drilled on favorable structures may find amply porous rock but be barren of oil or water. Salt water is found in quantity in the pools of Allen County and in the eastern side of Warren County, but little or no salt water is found in the Devonian or Silurian sands in other parts of the county.

The presence of porosity in the limestone is due to different

causes. The extreme eastern part of Warren County, and much of Allen County, are in an area where the porosity of the limestone is due to the solvent action of meteoric water which has entered at the outcrop of the limestone and has slowly percolated through the rock, dissolving the more soluble parts of the limestone and the saline residue on its travels down the dip of the strata. The distance from the outcrop to which this action has been effective is a function of the length of time the outcrop of these beds has been exposed to meteoric water. At the limit of the altered area there must be a large accumulation of water which is dammed back by the tight limestone which is yet unaffected by the meteoric water.[1] The extreme eastern side of Warren County is close to the line of separation of the porous area, produced by meteoric water solution, and the non-porous area, and the water trough must lie along this line. The occurrence of the oil and the great pressure behind it in the Moulder, Sledge, and adjoining pools showed this to be the true condition, and although considerable oil was recovered, the pools declined very rapidly and salt water in small or large quantities, depending upon the amount of the original pressure relieved, replaced the oil. The oil has evidently migrated from the fine-grained black shales to the underlying porous limestone through channels provided by joint planes and probably through incipient fissures which must be developed in rigid rock in folded areas such as are found in Allen and Warren Counties.

Outside of this area of porosity, there are several districts in the eastern half of the county in which there are a number of wells of small capacity. There is no pressure behind the oil and the accumulation is erratic. The small porosity of the rocks in these areas is probably due to recrystallization or dolomitization of the limestone. These wells do not form a group of any commercial importance.

In the producing area west of Bowling Green the Niagaran limestone appears to have ample porosity at the oil horizons to

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[1]The writer has given a more detailed description of this origin of porosity in his paper on the "Irvine Oil District, Kentucky." Resources of Kentucky, Vol. 1, No. 2, July 1919; and American Institute of Mining Engineers, Bull. 151, July 1919.

allow large accumulations. The porosity may be due to primary depositional conditions or it may be the result of secondary processes. The earthy appearance of much of the producing sand suggests the former; the crystallinity of some of the oil sand suggests the latter. If the sand porosity is the result of favorable depositional conditions and if the oil is indigenous to the Silurian limestone, the special conditions which must have existed during this stage of Silurian sedimentation were very local, for the small producing area is surrounded by a large barren area. If the source of the oil is the overlying black shale, the absence of oil in the Silurian limestone in the large barren area may be due to some condition which prevented its migration. Many wells barren of oil have gone through porous beds in the Niagaran limestone in which there is evidence of as much fauna from which the oil could originate as there is in the area where the Niagaran limestone is productive. If the limestone is the source of the oil, there appears to be no reason why the pools are not more generally distributed throughout the county and region. Also, since there is no hydraulic presure in the oil horizons, if the oil was formed within the limestone there is no possibility of migration and, therefore, no reason for accumulation on the higher structural points. Yet the best wells in the Niagaran sands conform closely to the structure. As noted before, wells on the structures usually find good sand conditions; many wells close by in the saddles and synclines have poor sand conditions, generally. May there not, therefore be some peculiar relation between structure and sand condition and localization of oil accumulation. The following is a possible explanation of the origin and accumulation of the oil in the sands underlying and within a reasonable depth beneath the black shale.

The folding which parallels roughly the escarpment ridge, the division between the plateau and the highland areas, was probably more acute than in any other part of this general district, and produced a series of paralleling domes with interdomal saddles and synclines. The folding is less intense as the distance increases from the escarpment ridge. Jointing in the rocks show a general northeast-southwest and lesser northwest-southeast direction, a phenomenon which shows the axes

of stress and strain. This pronounced folding very probably produced similar jointing and probably some fissuring of the hard limestone beds which underlie the black shale. Through such channels there would be a direct connection between the petroliferous black shales and water-saturated limestone beds below. The less dense limestones are evidently saturated for shooting frequently brings in some salt water which can be quickly pumped out. There is, however, no hydraulic pressure behind the water. The oil would pass from the denser and finer grained shale to the more porous water-saturated limestone bed on account of the difference in the capillary pressures of oil and water (a phenomenon of surface tension). The interchange would progress to the point where equilibrium was established, at which time no further migration of the oil could take place either downward or a return upward. Deposition from the ascending water might close many of the channels of migration even before equilibrium was established. Naturally there were some beds in the limestone which were more porous than others and, therefore, contained more water, and to these more porous beds the oil would have the greater tendency to migrate.

The areas of jointing and even fissuring would be most pronounced where the folding was the severest. These areas would, therefore, coincide with the domes and anticlines, and the saddles and synclines would be affected to a much less extent, and probably in many cases not at all. Therefore, the migration of the oil from the black shale to the sand would take place primarily on the structures and to a lesser extent on the flanks or in the saddles or synclines. Likewise, there would be less chance for accumulation of oil in paying quantities the farther away from the line of major structural disturbance, because of a decrease in the amount of jointing and fissuring. The oil primarily accumulating on the structures would remain there for the water in the saturated porous beds would prevent the oil moving down the dip by gravity.

Some wells were drilled on promising-looking structures and porous rock was found at the horizon which is producing at no great distance away. The absence of oil in these wells is probably due to a lack of fissuring or jointing which extended

from the shale to the sand. In other words, the area did not receive enough stress during the formation of the folds to create the requisite jointing or fissuring. Many other wells drilled on good structures have failed to find any porous beds in the limestone underlying the black shale. The absence of either the channels for migration or a porous, water-saturated bed would prevent accumulation in commercial quantities.

The following primary facts can be explained by the theory or origin and accumulation which has been advanced. Localization of the producing area; presence of the oil on domes and anticlines without water pressure behind it (a modification of the present general interpretation of the anticlinal theory); absence of oil in favorable structures which are underlain by porous strata below the black shale; absence of oil under so large a part of Warren County but under which the same fossiliferous Devonian and Silurian limestones and peroliferous black shale extend. It would be hard to explain any of these four primary facts by the theory that postulates that the oil is indigenous to the limestone in which the accumulation has taken place.

CONCLUSIONS

With no definite views on the probable origin and accumulation of the oil in Warren County, many geologists would recommend the drilling of all domes and terraces for these structures prevail where the oil pools are located. But many similar structures have been drilled without success and there must be reasons for such results. Accepting the theory of origin and accumulation as outlined by the writer, an endeavor to extend production should be along the line of most intense folding, which is close to the escarpment ridge, and domes should be selected along this line for initial tests. It seems reasonable to believe that the folding should extend for some distance both ways from the Bowling Green field, but how far favorable sand conditions extend cannot be foretold. If a working theory of the origin of the porosity in the Niagaran limestone could be advanced, a prediction as to the extension or limits of the field might be made, as was done in the "Irvine Oil District, Kentucky."[2]

[2]Op. cit.

TOPOGRAPHIC CRITERIA OF OIL FIELD STRUCTURE

BY V. E. MONETT

The effect which the structure of sedimentary rocks has upon the topography has long been recognized by all field geologists, and topographic criteria are now used in most rapid reconnaissance work. The large number of producing wells which were located by the so-called "creekologists," and by those pseudo-geologists who consider anticlines and domes as purely topographic features, have only served to emphasize the close correspondence of drainage lines and other topographic features to structural conditions.

The danger in using such criteria lies in the temptation to use them as a basis for detailed work, especially where outcrops are few and correlation is difficult or impossible. There are so many limiting conditions that a statement of a few of them seem desirable in order to award topographic features their proper place in structural mapping.

A brief review of the physiographic laws governing the relation of surface features to rock position shows that: (1) In a region of horizontal or nearly horizontal sedimentary rocks, the relief may be slight or considerable but the hills tend to be of uniform height and to have uniform slopes. The streams are more or less equally developed and are dendritic (tree-like) in appearance. (2) In gently folded sedimentary rocks (dips less than 20 degrees) the resistant rocks form low ridges with a gentle dip slope in the direction of dip of the rocks and a steeper slope in the opposite direction. The main streams flow in relatively straight lines following the weaker formations and in the direction of the strike. The hills may be of irregular shape and of different elevations and may have either synclinal or anticlinal structure. (3) In closely folded sedimentary rocks the hills are all of the narrow ridge type and may be long straight ridges or else zig-zag ridges. They are steep on one side and have gentler slopes in the direction of

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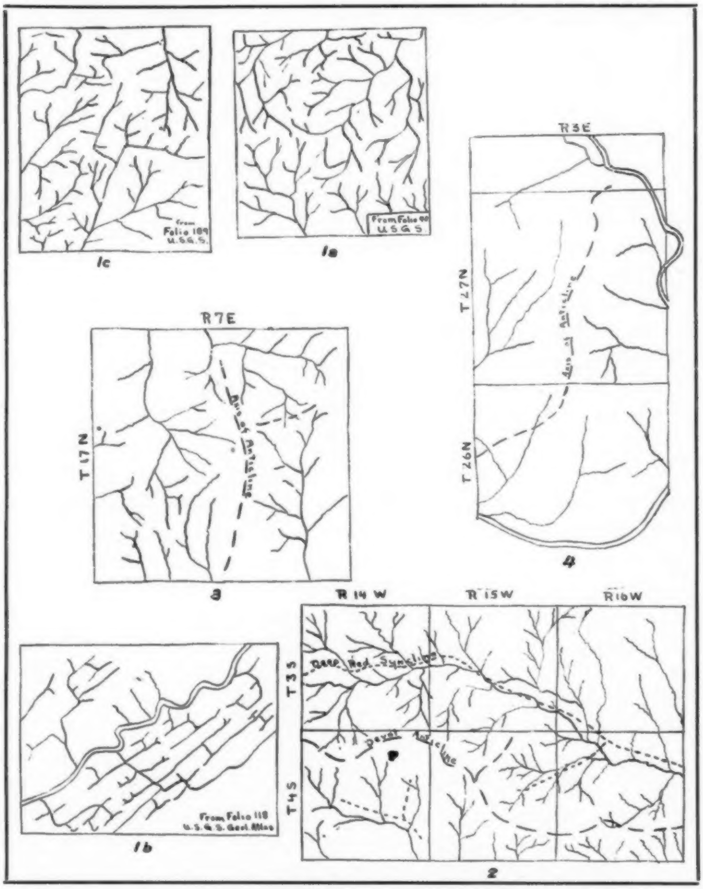

Plate I. *1a.* Drainage in horizontal rocks, central part of Wartburg, Tenn., quadrangle. *1b.* Drainage in closely folded sedimentary rocks, northwest part of Greenville, Tenn.—N. Cor. quadrangle. *1c.* Drainage in gently folded sedimentary rocks, Barnesboro, Penn., quadrangle. *2.* Reconnaissance map of the Grandfield district, Okla. (after Munn.) *3.* Shamrock dome, Okla. (after Trout). *4.* Part of Kay county, Okla. (after Trout).

dip of the rocks. The drainage is of the block type, with small weak streams flowing at right angles to the strike and the main streams running parallel to the strike and on the weaker rocks. The ridges are of unequal heights, and synclinal mountains are perhaps more common than anticlinal mountains.

These relations are clearly shown in Figures 1a, 1b, and 1c which represent actual drainage maps from selected areas. Figure 1a represents the dendritic drainage developed on horizontal rocks; figure 1b is an area of closely folded sediments and shows the characteristic block drainage; figure 1c, being developed on gently folded rocks, presents a drainage pattern that is a compromise between the other two types. The principal streams follow rather straight lines but the tributaries are somewhat dendritic.

Oil pools occur under all of the above three structural conditions. Rock outcrops and key horizons are usually abundant where dips are steep, so that topographic evidence is only made use of to the fullest extent where the type of folding is intermediate between case 1 and case 2 discussed above. A statement of the relation existing under such conditions would be about as follows: *When a considerable vertical section of more or less homogeneous sedimentary rocks are thrown into very gentle folds and eroded, the anticlines and domes will correspond approximately with the higher topographic areas, and the streams will tend to follow the synclinal axes.* True domes will give a radial drainage pattern.

Attention should be called to a number of qualifying phrases in this statement. In the first place it should be noted that if resistant sandstones or limestones are interbedded with soft shales, the tendency will be to develop escarpments facing the anticlinal axes, since the less resistant shales will be eroded much more rapidly than the other rocks. In the case of homogeneous sediments, or sediments which may differ in composition but have about the same resistance to erosion, the anticlinal axis is apparently not a place of weakness such as occurs along the axis of the sharp folds of more closely folded rocks. It offers the same resistance as the syncline and has the advantage of greater initial height. This advantage may be lost if the folding preceded emergence from below sea level, as slow

emergence would expose the anticline to erosion first. Another point which needs emphasis is that a single hill does not correspond to a dome but rather that a group of hills usually constitutes the "topographic high" area. Likewise a general drainage system, instead of a single stream, usually marks the location of the syncline. The maps (Plate I, figures 2, 3, and 4) will serve to illustrate these points. Only the drainage lines and the axes of the larger folds are indicated. Dozens of similar examples might be shown, but other structures, not very distant, may be found in which large streams cross the axis of the structure. Garber, Oklahoma field is a good example of this condition.

Even where resistant layers capable of forming escarpments occur, structures may be indicated by the direction of the scarp. In an area of general monoclinal dip, a semi-circular escarpment is good evidence of abnormal structure. Care is necessary to distinguish between meander scars of streams and true curving scarps due to rock position. The former can usually be identified by their habit of occurring first on one side of the stream and then the other. Gentle slopes which may be interpreted as dip slopes lend considerable weight to the evidence of curving escarpments when associated with them.

In areas of nearly flat topography the presence of structures may be indicated by the larger abrupt curves of the major streams. Numerous structures in Oklahoma along Arkansas, Cimarron, Canadian, and Red rivers have such a location, although it may be purely an accidental relation.

Perhaps no oil field better illustrates the value of topographic criteria than does the Gulf Coast field, where the earlier salt domes were located chiefly by the presence of low mounds or depressions and peculiar drainage relations. In the Pennsylvania fields, due to the complex structural history of the region, little dependence can be placed upon any such criteria. In the Warren quadrangle a low surface area is usually found to overlie the synclines, but in the Amity, Gaines, Elkland, and Tioga quadrangles the opposite condition usually exists.

In conclusion it may be said that the criteria of structure

afforded by streams, hills, escarpments, and other topographic features should be used only in reconnaissance work or else in those regions where other geological evidence is not obtainable. Even under such conditions it is doubtful whether the evidence is sufficiently strong to justify a favorable report or to warrant the expenditure of the money necessary to test a structure.

Note: Thruout this paper the word structure is used in accordance with the common oil field usage—i. e. structure favorable to the accumulation of oil, by which is usually meant dome or anticline. When used in any other way it is preceded by an adjective.

THE OIL SUPPLY OF THE UNITED STATES

By U. S. Geological Survey

A review of the producing, probable, and possible oil-bearing regions in the United States by a joint committee composed of members of the American Association of Petroleum Geologists and of the United States Geological Survey has resulted in an inventory estimate that 9 billion barrels of oil recoverable by methods now in use remained in the ground in this country January 1, 1922.

Unlike our reserves of coal, iron, and copper, which are so large that apprehension of their early exhaustion is not justified, the oil reserves of the country, as the public has frequently been warned, appear adequate to supply the demand for only a limited number of years. The annual production of the country is now almost half a billion barrels, but the annual consumption, already well beyond the half billion mark, is still growing. For some years we have had to import oil, and with the growth in demand, our dependence on foreign oil has become steadily greater, in spite of our own increase in output. It is therefore evident that the people of the United States should be informed as fully as possible as to the reserves now left in this country, for without such information we can not appraise our probable dependence upon foreign supplies of oil, on the expanding use of which so much of modern civilization depends.

Fortunately estimates of our oil reserves can be made with far greater completeness and accuracy than ever before. During the last eight years a large part of the territory in the United States that may possibly contain oil has been studied in great detail by oil geologists; wildcatting has spread through "prospective" into many regions of "possible" and locally even into regions of "impossible" territory; old fields have been definitely outlined and new ones discovered; and finally, improvement in methods and special training in the calculation of oil reserves and of the depletion of oil properties have been developed to meet the requirements of the tax laws. Accord-

ingly, in order that the public may get the fullest benefit of this newly available information, the United States Geological Survey in March, 1921, invited the American Association of Petroleum Geologists to co-operate with it in a review of the producing, probable, and possible oil territory of the United States and in the compilation of an estimate of the petroleum remaining in the ground and recoverable by present methods. This invitation was promptly accepted by the association, which designated a number of its ablest members of well-known wide experience, good judgment, and high professional standing to serve with the oil geologists of the Survey as members of a joint committee.

The committee responsible for the original preparation of the estimates and finally for the adjustment and revision of the results in joint conference comprised F. W. DeWolf, state geologist of Illinois; W. E. Wrather, of Dallas, Tex.; Roswell H. Johnson, of Pittsburgh, Pa.; Wallace E. Pratt, of Houston, Tex.; Alexander W. McCoy, of Bartlesville, Okla.; Carl H. Beal, of San Francisco, Calif.; C. T. Lupton, of Denver, Colo.; Alexander Deussen, of Houston, Tex.; K. C. Heald, of Washington, D. C.; and G. C. Matson, of Tulsa, Okla., all representing the American Association of Petroleum Geologists; and, for the Federal Survey, David White, chief geologist, Chairman; W. T. Thom, jr., A. E. Fath, Kirtley F. Mather, R. C. Moore, state geologist of Kansas, and K. C. Heald. Mr. Heald represented both the Survey and the Association. These men were assisted in subcommittees by a large number of the leading oil geologists of the country, including oil-company geoloists, directors of state geological surveys, and consulting geologists, who were especially familiar with the regions considered. All these co-operated whole-heartedly in the canvas of our oil reserves, and many oil companies also furnished confidential data for use in the preparation of estimates.

The calculations of the oil reserves in the proved and discovered fields are reasonably reliable, and those for regions regarded by the geologist as embracing "probable" future oil fields are based on all the available data and are entitled to high respect, but the committee wishes it most clearly understood that the estimates of oil in "possible" territory are abso-

lutely speculative and hazardous and that, although they represent the best judgment of the geologists, they nevertheless may be, at least in part, wildly erroneous. The questions involved are not only how much a particular doubtful region will yield, but whether it will furnish any oil whatever. On the whole the estimates are undoubtedly the best that have ever been made for the United States and better than have hitherto been prepared for any oil country or district of the world.

The estimates for local areas, fields, or districts have been consolidated by States, group of States, or broad regions in the case of nonproductive States.

Estimated oil reserves of the United States, by states or regions

	Millions of barrels.
New York	100
Pennsylvania	260
West Virginia	200
Ohio	190
Indiana and Michigan	70
Illinois	440
Kentucky, Tennessee, northern Alabama, and northeastern Mississippi	175
Missouri, Iowa, North Dakota, Wisconsin, and Minnesota	40
Kansas	425
Oklahoma	1,340
Northern Louisiana and Arkansas	525
Texas, except Gulf Coast	670
Gulf Coast, Texas and Louisiana	2,100
Colorado, New Mexico, and Arizona	50
Wyoming	525
Montana, Nebraska, and South Dakota	100
Utah, Nevada, Oregon, Washington, and Idaho	80
California	1,850
Eastern Gulf Coastal Plain and Atlantic Coast States	10
	9,150

The New England States are regarded as too unpromising to deserve consideration. Most of the northern peninsula of Michigan and the State of Minnesota are placed in the same category. The small quantities allocated to some other states indicate how little hope these geologists have of finding extensive oil fields in them. Some of these very doubtful regions will

give no oil, but others will make good the deficiencies. The estimates are as a whole distinctly conservative.

Of the total estimated oil reserves of the United States, amounting in round numbers to 9 billion barrels, 5 billion barrels may be classified as oil in sight and 4 billion barrels as prospective and possible. Rather more than 4 billion barrels should be assigned to the heavy-oil group. These oils will be recovered mainly in the Pacific Coast, Rocky Mountain, and Gulf States. The contents of the Lima-Indiana region, which yields oil of a distinctive type, are estimated at 40 million barrels. In general the so-called paraffin oils of moderate and high grade, as contrasted with the heavier oils, amount in all to about 5 billion barrels. The estimated reserves of high-grade oils of the Appalachian States are about 725 million barrels.

The estimated reserves are enough to satisfy the present requirements of the United States for only 20 years, if the oil could be taken out of the ground as fast as it is wanted. Should these estimates fall even so much as 2 billion barrels short of the actual recovery, that error of 22 per cent would be equivalent to but 4 years' supply, a relatively short extension of life. However, the committee expressly decries the too frequent assumption that inasmuch as the estimated reserves appear to be sufficient to meet the needs of the country at the present rate of consumption for 20 years, therefore the reserves will be exhausted at the end of that time or, at most, a few years later. This assumption is absolutely misleading, for the oil pools will not all be found within that length of time, drilling will be spread over many years, as the pools are found, and the wells can not be pumped dry so quickly. Individual wells will yield oil for more than a quarter of a century, and some of the wells will not have been drilled in 1950. In short, the oil can not all be discovered, much less taken from the earth in 20 years. The United States is already absolutely dependent on foreign countries to eke out her own production, and if the foreign oil can be produced, this dependence is sure to grow greater and greater as our own fields wane, except as artificial petroleum may be produced by the distillation of oil shales and coals, or some substitute for petroleum may be discovered.

All the estimates except those for one region, noted below, include only the oil recoverable from the ground by present methods, but it is practically certain that the percentage of oil to be recovered from the American oil fields will be vastly increased by the application of new and improved methods of recovery. At present, however, this phase of production may be regarded as in the experimental stage. Little has been definitely determined as to the applicability of "air pressure," "water drive," "gas pressure," "vacuum extraction," and other new methods to different regions, with their variation in conditions, or to the increase in production to be counted on from the use of these methods. The committee therefore feels that at present any estimates of such possible additional recoveries would probably contain errors enormously greater than those inherent in the estimates made on the basis of methods now in use. In only one region are the geologic conditions so well known and the experience with improved methods on a commercial basis so extensive and so long continued as to justify the formulation of estimates based on the results obtained. This is the region in northwestern Pennsylvania and southwestern New York where the "water drive" is now employed to obtain oil from the Bradford sand, which was supposed to be largely exhausted. Under the peculiar conditions there the use of this method will result in the recovery of a large quantity of oil that can not be recovered by ordinary methods of production. Allowance for the additional oil thus recovered has therefore been made in the estimates. It has already been found, however, that this method is not applicable to some other districts, and accordingly no allowance has been made for possible additional recovery through its use where its suitability to the local conditions has not been actually demonstrated.

In the light of these estimates as to the extent of our supplies of natural petroleum, the joint committee points out the stern obligation of the citizen, the producer, and the Government to give most serious study to the more complete extraction of the oil from the ground, as well as to the avoidance of waste, either through direct losses or through misuse of crude oil or its products.

DISCUSSION

ON THE STRATIGRAPHY OF NORTHEASTERN ARIZONA

In a recent privately published pamphlet entitled "Oil possibilities of the Holbrook area in northeast Arizona," Mr. Dorsey Hager has placed on record stratigraphic conclusions concerning this very interesting portion of the Colorado plateau country which are so widely at variance with the studies of other workers that, although hardly a subject for detailed review, discussion of Mr. Hager's chief correlations and his method of reaching them is called for. Portions of the paper have more recently appeared in the Mining and Oil Bulletin (Los Angeles), January and February, 1922, in which there appear very radical revisions. Through the courtesy of the author a "corrected copy" of the complete article has just been transmitted to the present writer.

Without reference to other contents of Mr. Hager's contribution, attention may be directed to the discussion of stratigraphy.

The geological formations of northeastern Arizona range in age from the Pre-Cambrian to the Tertiary but the units with which there is chief concern are between the Cambrian and the Cretaceous. The well known Grand Canyon region divisions which come within this interval include the Redwall limestone, Supai formation, Coconino sandstone, Kaibab limestone, Moenkopi formation Shinarump conglomerate, Chinle shale, Laplata sandstones and the McElmo formation. These, or equivalent stratigraphic divisions, are very widely distributed throughout the Navajo county of northeastern Arizona, (where they have been studied chiefly by Gregory[1],) southern Utah, southwestern Colorado and northeastern New Mexico. Holbrook is about 130 miles southeast of the Grand Canyon and near the southern edge of a broad, very gentle synclinal basin which involves the central part of the Navajo country. In the vicinity are exposed the Chinle shale, Shinarump conglomerate and the Moenkopi formation while not far distant are typical exposures of Kaibab limestone and the Coconino sandstone. In the escarpment of Mogollon Mesa to the south are exposed beds belonging to the Supai and Redwall. The section of this region is therefore essentially similar to that of the Grand Canyon country.

In southeastern Utah along San Juan river these are well exposed a series of reddish sandstones and shales and beneath them, in the vicinity of Goodridge, a considerable thickness of fossiliferous Pennsylvanian limestone. The latter, with some included sandstone and shale has been named by Woodruff[2] the Goodridge formation. The Goodridge formation is well known because it contains oil, but because a broad syncline

[1]Gregory, H. E. Geology of the Navajo country, U. S. G. S., Prof. Paper 93, 1917.
[2]Woodruff, E. G., Petroleum and Natural Gas in Utah, U. S. G. S., Bull. 471 p. 76, 1912.

which lies between the San Juan oil field and the Grand Canyon carries the Pennsylvanian strata beneath the surface, it has not been possib'e to establish definitely the relation of the Goodridge beds to the Carboniferous deposits in the Grand Canyon district. The Goodridge, at its type locality, is overlain by red sandstones and shales which Woodruff and Gregory[3] referred to the Moenkopi. Unlike the Moenkopi of other areas, however, there are in the beds above the Goodridge very massive sandstones, one of which on account of its remarkable development in the Canyon de Chelly has been called the De Chelly sandstone.[4] The De Chelly sandstone is immediately overlain by the Shinarump conglomerate.

Following this brief introductory statement, it may be noted that Mr. Hager proposes to correlate the De Chelly sandstone of the Navajo country with the Coconino sandstone of the Grand Canyon region,—or rather the upper part of the De Chelly with the Coconino and the lower part with a part of the Supai. Presumably then, the Goodridge limestones are equivalent to the Redwall limestone of the Grand Canyon section, a correlation which is accordingly made. Mr. Hager is more definite. Referring to the "corrected copy" (Fig. 4) it is noted that the "Upper Redwall," is equqivalent to the "Upper Goodridge" and that both are to be regarded as "Basal Supai"; the "Middle" and "Lower Goodridge" represent the "Lower Redwall." Unfortunately, however, the limitations of these subdivisions, their relation to the horizons of Pennsylvanian and Mississippian fossils which have been reported by other investigators and the basis for establishing the correlations are not indicated. Above the "Coconino" in the San Juan area Mr. Hager records Moenkopi, Holbrook (a new division), Shinarump and Chinle. Although the presence of a nearly normal section of Supai and Coconino beds above the Goodridge in the San Juan region is not prerequisite to correlation of the Goodridge strata with the Redwall, it appears to be Mr. Hager's conclusion that if the Goodridge and Redwall are equivalent, the Supai and Coconino must also be present in the San Juan district and that they are in fact represented by the shale and massive sandstone which Gregory and Woodruff regarded as Moenkopi and De Chelly, respectively. If the De Chelly is Coconino and the Goodridge is Redwall, oil may be sought in the Redwall at other places, as near Holbrook, and the depths involved in drilling which starts even above the De Chelly are not great.

The present writer does not propose in this discussion to take up in detail the validity of Mr. Hager's correlations. These are in part probably correct and in part erroneous. It may be noted that the interval reported by Woodruff betwen the base of the Laplata sandstone and the top of the Goodridge in the San Juan area is approximately the same (3000 feet) as that between the base of the Laplata and the top of the Redwall in the Grand Canyon district, and similarly as that between the

[3]Ibid.
[4]Gregory, H. E., loc. cit.

base of the Laplata and the top of the deep limestones encountered in the 3212-foot test of the Ohio Oil Company in the Circle Cliffs which started near the top of the Kaibab limestone. It appears certain that the considerable thickness of sandstone beneath the Kaibab limestone in the Circle Cliffs, about 65 miles northwest of the San Juan district, represents Supai and probably Coconino. It is very probable that equivalents of these units are also present in the San Juan district. However, that the Coconino is equivalent to the upper De Chelly, or to any part of the De Chelly may be doubted. Recent studies by H. D. Miser in the San Juan canyon and by Sidney Paige in the Cataract canyon of the Colorado River may throw important light on this point, but it appears very inadvisable to assert equivalence on such slender evidence or lack of any evidence—for Mr. Hager offers none—as is presented. Indeed, it is very uncertain in the paper under discussion what is meant by De Chelly. The typical De Chelly at the Canyon de Chelly, as described by Gregory[5], immediately underlies the Shinarump conglomerate. The sandstone designated De Chelly in Mr. Hager's "corrected copy" and which is correlated with the Coconino underlies the Moenkopi (Hager) and is apparently quite distinct from another, much thinner sandstone above the Moenkopi and beneath the Shinarump which was marked in the first edition as De Chelly.

There are some errors in the premises used in the paper as a basis for interpretation of the historical geology of the region, such as the statement[6] that Pennsylvanian rocks are absent in the Nacimiento Mountains of northwestern New Mexico. The writer has obtained large collections of typical Pennsylvanian fossils on the north and southeast flanks of this range.

The deficiencies which take most of the stratigraphic value from Mr. Hager's paper are a failure to submit evidence for hardly any of the correlations and a lack of precision in description of the stratigraphic units under discussion which in several instances makes it almost impossible even for the reader who is acquainted with the geology of the region, to follow. The presence of very glaring and almost self-evident miscorrelations in the first issue of the pamphlet, such as the reference of the upper part of the Navajo sandstone (Laplata) in Comb Wash, near Goodridge, Utah, to the Coconino, and the very large revisions in the "corrected copy" suggest that the evidence on which the entire paper is constructed is not very definite or thoroughly digested. An error, similarly suggestive of rather superficial acquaintance with the stratigraphic problems involved, to the effect that Woodruff and Gregory correlated the Coconino and Kaibab with the Moenkopi in the San Juan area has been corrected.

RAYMOND C. MOORE

[5]Gregory, H. E., Geology of the Navajo country, U. S. G. S., Prof. Paper 93, p. 32, 1917.

[6]Hager, Dorsey, Oil Possibilities of the Holbrook area, p. 22.

GEOLOGICAL NOTES

NOTES TO INVENTOR GEOLOGISTS

The members of the Association with an inventive type of mind, will perhaps be interested in the following ideas that have suggested themselves to the writer, who has carried them out in the crude way illustrated by the accompanying photographs.

The idea of a traveling machine that would automatically map to scale all of the roads driven over, is a dream that has occurred to many geologists doing reconnaissance work in unsectionized states. Theoretically such a machine is possible, using a gyroscopic compass to keep the map at all times properly oriented, and using a small wheel driven by a flexible cable to plot the distances passed over. Correspondence with the Sperry Gyroscope Company disclosed however that such an instrument cannot be adapted to an automobile, as the disturbances to the gyroscope caused by the jolting, rapid acceleration and retardation would soon deflect the instrument from its oriented position. So it seems that the self orienting mapping machine for geologists must still remain a dream.

If the self orienting feature is dispensed with, it is a comparatively easy matter to devise a machine that will plot the direction and distances driven over if the map board be kept properly oriented by hand.

For the geologist afoot, a traversing machine can be constructed to be operated in a manner similar to a tally register, but plot graphically the distances and courses of the traverse. The first photograph shows a crudely constructed machine for this purpose. A spring rachet is pressed by the thumb for every double pace. The rachet turns a screw, by means of which the recording pencil is slowly moved forward over the paper. The paper must be kept oriented by hand, revolving it around the pencil point as a center, so that the north-south line on it is kept parallel with the compass needle. In the hands of a man accustomed to pacing, very nice closures may be had with this simple instrument and the mind and hand freed from all counting and plotting.

The next instrument to be described has been given the awe-inspiring name of an intermittently recording microbarograph. This instrument was designed to record on a moving strip of paper the magnified fluctuations of an ordinary five inch surveying aneroid. This record then affords a means of correcting the readings of a twin aneroid carried by the geologist, who by noting the time of each reading is enabled to correct his readings in the evening without the usual systems of benchmarks and time corrections.

Since the sensitive mechanism of an aneroid is not strong enough to drag a pen over the paper, the record must be plotted without any friction whatever, the needle swinging freely except at the moment of record. The second illustration shows that this has been accomplished by adapting the clockwork recording mechanism from a thread type recording pyrometer to record the movements of the aneroid. The short needle of the

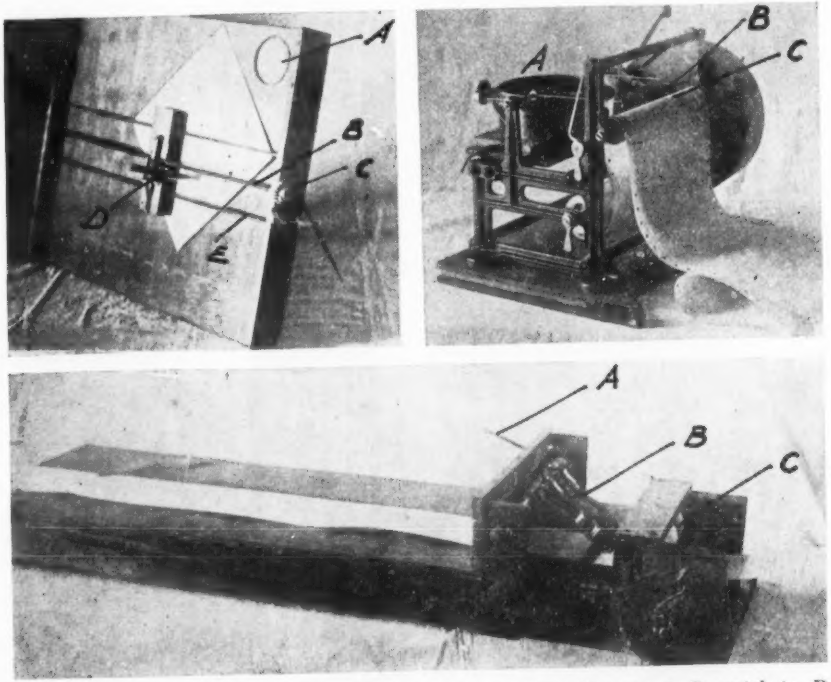

Plate I. *Upper left*, Traversing machine. (A, compass; B, screw; C, ratchet; D, pencil; E, guide rod). *Upper right*, Microbarograph. (A, five-inch aneroid; B, recording lever which falls at half-minute intervals; C, long needle of aneroid). *Lower*, Log-plotting machine. (A, pen-shifting lever; B, battery of pens; C, top roller.)

aneroid is removed and replaced by a longer one, this being the only change necessary to the aneroid. The long needle is passed over the inked thread and under the recording lever which falls at half minute intervals and forces the needle down for an instant against the inked thread which in turn records a point on the slowly moving paper. This paper moves by clockwork, one inch per hour, and the many points form a continuous line. Barometric changes of less than five feet can be read from the record and the record is wide enough to allow a range of five hundred feet of barometric pressure.

For the best results the aneroid carried by the geologist should be carefully matched with the one used for recording, by testing them together in a vacuum box until they are adjusted to work in unison.

The following is a brief outline of the method of field work with such an equipment. The barograph is transported to a place near the center of the area to be worked the needle being removed for the purpose. The needle is then replaced so that its reading on the ruled record coincides with the reading of the field instrument. The geologist then winds up the clock and goes into the field. With every elevation he takes, he also records the hour and minute. In the evening these readings are quickly corrected from the record of the barograph. To prevent the barograph from being molested it may be marked with a notice "Warning! Infernal Machine! Hands Off!"

The writer regrets that having but one instrument at his disposal he has never had an opportunity of thoroughly testing the practical applications of this method in the field. Many geologists believe that local disturbances would make it impossible for the worker to work more than a mile away from the barograph. Others are of the opinion that the so-called "holes in the air" reported by some aneroid workers, are due entirely to the use of small and inaccurate instruments.

The third instrument to be described is a log-plotting machine, made originally for Mr. M. J. Munn but not yet perfected. The most irksome task of the indoor geological worker is the plotting and coloring of the many well logs necessary in correlation work. A machine to do this work should be received with open arms by all who have had much of this work to do.

Let us analyse some of the features a successful log-plotting machine should have. It should be so designed that logs can be plotted by the "touch" or "sound" method and the eyes remain on the copy to be plotted and not needed for operating the machine. It must be accurate, it must plot thin formations as well as thick, it must not blot, it must be fool proof.

The third photograph shows an attempt to design such a machine. It does not fulfill all of the above requirements but may serve to stimulate the thoughts of others along this line.

The blank paper form, with the usual rulings is fed through the machine by a pair of small rollers operated by a small crank. One com-

plete revolution of the crank moves the form over a space corresponding to exactly 100 feet. Ten notches in the large disc mark the ten foot spaces with an audible click and with a little practice smaller divisions are easily estimated.

As the log form passes through the machine the various colors are wiped on from a battery of pens. Changes from one color to another are instantly made with a slight motion of the left hand.

A thin ribbon kept moist with ink from a thick flannel reservoir over each pen, spreads a broad even color over the spaces desired. If the ribbon is properly inked there is no surplus to cause blotting. A notch in the top roller however, allows the freshly inked area to pass through without contact with the roller. It has been found that the revolving rollers will measure off the depths so accurately that slight errors in the printed form are often brought to light. If the pens could be made to work as satisfactorily, everything would be lovely. The first pens tried were broad shading pens. They were too liberal with the ink and they had a limited capacity. Next ribbons were tried, fed from a moist flannel pad above. This method was suggested by the operator of a ruling machine, the pens of which are fed from such a reservoir. The skill required in keeping the reservoir properly saturated is a serious defect in the use of this method. The machine illustrated is equipped with pens of this type and it works nicely in the hands of a skilled operator but is sure to blot in the hands of others.

One of the surest ways to avoid the dangers of blotting would be to apply the colors by impact through colored ribbons as is done by the typewriter. This however makes the machine much more complex since several colored ribbons must be used and means added for giving each ribbon a progressive movement to provide fresh surface. The point to be brought out is, that the development of a successful log-plotting machine is not impossible by any means, and it is hoped that this article has stimulated the minds of the inventor-geologists so that the solution to this problem and some of the many other problems that daily present themselves, may soon become accomplished facts.

W. E. Dodge.

HAYNESVILLE FIELD, LOUISIANA

Development to date in the Haynesville field shows the existence of from two to three sands ranging through a vertical distance of from 20 to 50 feet. These sands are usually separated by sandy shales which in many instances form extremely hard caps. The oil appears to be more generally confined to the middle sand. The upper sand is very compact and rarely porous enough to contain either much oil or water. The lower sand is more porous but does not appear to be completely saturated with fluid. On the edge of the pool salt water may occur in all of these sands. In completing a well it appears desirable

not to drill into the lowest sand, lest in its unsaturated condition it drain off some of the oil from the upper sands, even though the well be located high on the structure. The salt water line is being defined in the south part of the pool with surprising regularity. A plane approximately 2500 feet below sea level seems to mark this horizon. It has been found that edge wells can be made most profitable by drilling into the oil sand only two or three feet. Even a foot or two below the critical level has led to a large influx of edge water with the oil. Packing off this water has helped somewhat.

L. P. TEAS.

December 12th, 1921.

AGE OF THE PRODUCING SAND, ELDORADO FIELD, ARKANSAS

The U. S. Geological Survey on February 7th, 1922, published a press notice regarding the age of the producing sand in the ElDorado field, which is quoted in the following paragraphs:

"Dr. L. W. Stephenson, of the United States Geological Survey, has determined the age of the producing oil sand definitely at the horizon of the Navarro formation, which is equivalent to nearly all of the Marlbrook marl, the Nacatoch sand, and the Arkadelphia clay, three formations belonging to the Upper Cretaceous series. A small fragment of the cuttlefish *Belemnitella americana* was obtained at a depth of 2,129 feet from the Gladys Belle Oil Co's. Fitzgerald No. 4 well, in sec. 8, T. 18 S., R. 15 W. The known range of this genus and a supplementary study of the formations passed through by the wells strengthen the conclusion that the sand is the Nacatoch.

A few wells on the outskirts of this field have reached a sand about 400 feet below the Nacatoch. This deeper sand lies between the Nacatoch and the Blossom sand of the drillers. Proof is furnished by a specimen of *Crenella serica* (?) a small mollusk, found in a section of a core obtained at a depth of 2,552 feet from the Cooper-Henderson Oil Co.'s Hammond No. 1 well, in sec. 19, T. 17 S., R. 15 W. This species is common in beds of Navarro age but has not been found in beds older than the Navarro, except perhaps in a formation in New Jersey, where certain specimens were found that are questionably identified. The stratum from which the specimen found in the Hammond No. 1 well came is believed to be a part of the Marlbrook marl."

OCCURRENCE OF LIMESTONE IN NORTHEASTERN GARVIN COUNTY, OKLAHOMA

Near the southeastern corner of the northeast ¼ of the southeast ¼ of section 2, T. 4 N., R. 3 E., is found an outcrop of rather massive grayish white limestone. It is located in a small creek and for that reason is more or less limited in extent. The rocks surrounding this outcrop are Permian Redbeds, and though one would expect to find the limestone

on the hills within a half mile to the east of the creek, such is not the case.

The limestone is a very hard, close grained rock, heavily charged with calcite, rather brownish gray in fresh fracture though weathering white. There is about four feet of limestone exposed, below which is at least three feet of shale of practically the some color.

A careful search failed to bring to light any fossils by which the limestone could be identified, though there is a little doubt but that it is older than Permian From general appearances the rock seems to be even older than Pennsylvanian though without fossils it is impossible to determine its exact age. The fact that it is older than Permian would prove that there is an unconformity of no mean proportions between the Permian and Pennsylvanian and this is of great importance both economically and technically.

About five miles to the east in T. 4 N., R. 4 E., is found an extensive outcrop of limestone which strikes almost due northeast and southwest. This limestone is dipping northwest at the rate of sixty to eighty feet per mile which is a higher rate of dip than is found in the Redbeds to the northwest.

HARVE LOOMIS.

REVIEWS AND NEW PUBLICATIONS

OIL LAND DEVELOPMENT AND VALUATION

By R. P. McLaughlin

McGraw-Hill Book Company, 1921.

The viewpoint of the author of this comprehensive little treatise is expressed in the preface, which informs the reader that "the information presented is based upon some ten years of investigations, a portion of which were made while administering the oil and gas conservation laws of the State of California. The operating conditions in the oil fields of California are of great diversity and embrace the general conditions obtaining elsewhere. Most of the obstacles encountered in the various fields of the world occur in some California field. The general principles involved in oil production are applicable to all oil fields."

The contributions of Mr. McLaughlin to the technology of oil production and conservation while he was State Oil and Gas Supervisor of California are known for their soundness and value in engineering practice. It cannot be disputed that the difficulties which are encountered in California oil fields are great, and in many cases extreme. For this reason the machinery and the methods used in drilling and production in Eastern and Mid-Continent fields had to modified to meet the requirements of Pacific Coast conditions. This evolution affected rig building, the rotary drilling outfit, the underreamer, calf wheel and many other parts of the oil operator's apparatus. It is advantageous if improvements in machinery and in methods which have been developed in the California fields may be applied in every other field where conditions permit, for the oil business is no longer sectional.

With these thoughts in mind the experienced geologists, engineer or oil producer anywhere may apply to his particular problems facts and principles which are presented in Mr. McLaughlin's book. He will overlook the fact that it is distinctly a California product which only casually mentions other districts.

The book contains six chapters. Chapter I, Development Program, includes important points relative to the spacing of wells and the rate and method of development in planning oil field operations. Chapter II, Drilling of Wells, discusses the importance of a thorough understanding of geological conditions, and treats of methods of conservation by proper handling of the oil and gas and by exclusion of water. Chapter III, Assembling Information regarding Underground Condiions, contains much valuable material relating to graphic logs maps, cross-sections, peg models and progress reports. Chapter IV, Production of Oil, considers production record forms and graphs, most of which could be taken as models for leases in almost any field in the United States. Chapter V, Repairing, Deepening and Abandoning Wells, contains field maps and describes examples from California which are of general interest in relation to this subject. Chapter VI, The Value of

Oil Land, discusses the latest engineering methods of determining the amount of available oil, cost of production, drilling, pumping and market price of oil.

While, as has been indicated, the discussions apply mainly to California conditions, at least one half of the work pertains to subjects and principles which are general in application, and of the balance there is little which cannot be of interest to those outside of the Pacific Coast fields. Throughout the book there are many diagrams, cross-sections, and other illustrations which add to the value of the discussions.

Detailed review of the subjects considered would no doubt suggest many points which might have been treated somewhat differently and there are also minor corrections. An instance which would possibly be noted by some readers is the statement (p. 48) that use of the mud-laden fluid dates from 1915 when it was introduced by the U. S. Bureau of Mines in Oklahoma. It was actually introduced by members of the Bureau as early as 1913. There is an impression that some parts of the book, such as the last chapter, might very desirably have been elaborated.

H. B. GOODRICH.

Tulsa, Okla., Feb. 1, 1922.

OIL AND GAS PROSPECTS IN THE VICINITY OF BUTTONWILLOW, KERN COUNTY, CALIFORNIA

BY R. M. FERGUSON

(Monthly Chapter Seventh Annual Report State Oil and Gas Supervisor, California State Mining Bureau, September, 1921.)

This is a short article designed to present the significant facts that have been revealed by the drilling near Buttonwillow, and the writer's conclusions concerning them.

Drilling in Buttonwillow resulted from the discovery that the productive oil zone in the Elk Hills to the west was not more than 3,000 feet below the top of the McKittrick formation. This fact, combined with evidence indicating that anticlinal structure was present in Buttonwillow, seemed justification for the tests. The conclusion that anticlinal structure exists at Buttonwillow is based upon the surface relief which shows a low swell in approximate alinement with the Coalinga, Kettleman Hills, and Lost Hills structures; the drainage lines in the bottom of San Joaquin Valley, which in the vicinity of Buttonwillow are parallel and margin the flanks of the supposed anticline instead of cutting across it; distinct dips to the southwest observed in alluvial deposits as opposed to dips to the northeast revealed by the logs of water wells; and the lack of artesian head on the ground water in this area, while at either side flowing wells could be obtained, as shown by Water Supply Paper 222 of the United States Geological Survey. After drill-

ing for oil was started core drilling was done by the Shell Company of California at the north end of the supposed anticline, and it is reported that anticlinal structure was proved by this means.

The beds passed through by such wells as have been drilled may be divided on the basis of lithology into three distinct groups: (1) 600-1200 feet of coarse sand with thick partings of yellow clay; (2) 1400 feet of blue clay with beds of hard sand; (3) carbonaceous shale beds. In these carbonaceous beds are fossils which appear to resemble forms found in the upper Etchegoin and Tulare formations in the Kettleman Hills. A bed of lignite reported in wells in the Elk Hills comes a short distance above the oil-bearing zone, and the writer has correlated the lignitic beds in the two districts.

Indications of oil in the Buttonwillow wells are confined to strong flows of natural gas which analyses show to contain a considerable proportion of ethane, and therefore possibly propane and butane, since these two hydrocarbons are commonly determined by analysts in terms of ethane; and to oil showings revealed by chloroform tests of drill cuttings. The latter can not be considered absolute evidence of the presence of even a small quantity of oil, since it has been found that resins and waxes that may be present in peat or lignites will give a discoloration of chloroform that is practically indistinguishable from that which results from petroleum.

The heavy flows of gas from the lignitic shales and sands in the Buttonwillow area raise the question as to the source of the oil and gas, not only in the Buttonwillow district, but also in other parts of California, and the writer expresses the belief that oil and gas in several of the San Joaquin fields have their origin in these shales rather than in the underlying diatomaceous beds of the Monterey.

Thus far no production test has been made on any of the wells, and until such a test is made no conclusions can be drawn regarding the possible productivity in the territory.

Jan. 1, 1922. K. C. HEALD.

SALT DOMES OF NORTHEASTERN TEXAS

BY CHAS. A. CHENEY.

Oil and Gas Jour., Jan. 6, 1922, pp. 82-83

In this article Mr. Cheney advances theories, that are radically at variance with those of previous writers, to account for the formation of the salt domes of northeastern Texas. He presents the basis for his belief very concisely, and touches on its economic significance.

The major contention is that the Butler, Palestine, Keechi, Brooks, and Steen domes lie along the crest of an anticlinal fold. Their exposure is assumed to be due in part to cross folding of this anticline, and in part to erosion, which took place in pre-Tertiary time. The salt is considered a bedded deposit, originating in the interval between the deposition of

lower and upper Cretaceous, or else during lower Cretaceous time, and its apparent vertical thickness is ascribed to close folding.

Upon this theory Mr. Cheney bases conclusions that "the immediate vicinities of the domes are not favorable for exploration for petroleum in the upper Cretaceous"; that along the trend of this theoretical anticline there may be hidden domal areas of promise; and that "possibilities—would increase as one went north on the Butler-Steen anticline."

It is noteworthy that the above theory is based entirely upon assumptions none of which can at present be verified, and some of which seriously tax the imagination and credulity. First it is assumed that there is much more intense anticlinal folding in the great synclinal area where these domes are situated, than has taken place along the edges of this syncline. The distortion called for by this postulated folding is comparable to that in the Rocky Mountains, for Hopkins tells us that the beds on at least one of these domes have been elevated 3,000 feet—many times the elevation on any known fold involving Cretaceous strata in eastern Texas. In fact Mr. Cheney's theory calls for the fold to be closed in places—Appalachian stucture within a few miles of the gentle dips of the Mexia anticline.

Profound erosion is demanded in the interval between the close of Cretaceous sedimentation and the beginning of Wilcox sedimentation. This erosion was called on to develop peaks, smoothly conical, or indeed almost cylindrical for their flanks must have approached verticality in places. They did not need the surprising feature of a salt bed capping them or lying but a short distance beneath their crests to make them unique among physiographic forms.

Perhaps most difficult of all to follow is the reasoning relating to the origin of the salt. The author concluded that it was laid down in lower Cretaceous time or in the interval between the deposition of lower and upper Cretaceous, supporting his belief by a citation of the occurrence of gypsum in the upper Cretaceous over the Sabine uplift. To get the salt to its present position in contact with upper Cretaceous strata without invoking either intrusion or solution and redeposition, it must either by surrounded by a circular fault, or else the salt mass itself was carved into mountains during a period of erosion. Either of these assumptions may, with consistency, be added to the previous ones.

Mr. Cheney points out an alignment of a number of salt domes which parallels the Balcones fault, and is at least approximately parallel to the line of anticlines of which the Mexia fold is one. Although the theoretical anticline he would have accompany this alignment cannot be considered seriously unless his assumptions are radically modified, there can be little doubt that this trend is of possible economic significance. It probably indicates the presence of a continuous zone of weakness along which there may be faults and folds of great importance.

K. C. HEALD.

LOWER CALIFORNIA

El Boletin del Petroleo, Vol. 11, No. 6, June 1921, published by the Secretaria de Industria, Comercio y Trabajo, Mexico City, and procurable from him for $1.00 U. S., contains an article of 74 pages with two colored geologic maps and a number of photographs on Lower California. The title is "Informe sobre la geologia y la existencia de los yacimientos petroliferous en el distrito sur de la Baja California," by Miguel Bustamante. The geological map in five colors is very fanciful and inexact. Mr. N. H. Darton has also published "Geologic reconnaissance in Baja California," in the Journal of Geology for Nov.-Dec. 1921.

ISTHMUS OF TEHUANTEPEC

The same Boletin for April, 1921 contains a reprint of a paper by Arthur H. Redfield in Eng. & Min. Jour., Mar. 19, 1921. The title is "La industria del petroleo campos petroliferous mexicanos en el istmo de Tehuantepec." The article is accompanied by a map in four colors 8½x13 inches showing the location of the Isthmian salt domes. A deep sand oil well is reported to have been completed in December, 1921, on the Concepcion dome. The Secretary also publishes a map of the same region in four colors scale 5 km. to 1 inch, sixe 14x25 inches, entitled "Plano de la Zona petrolifera del Istmo," another map, "Plano del Canton de Tuxpan" same scale, size 18x24½ inches and a third map "Carta de la zona petrolifera del norte de Veracruz y del las regiones colindantes," scale 10 km. to 1 inch, sixe 26x33 inches, each, in four colors, price $1.00 U. S.

AT HOME AND ABROAD

MR. MAX A. PISHEL has returned to Tulsa and resumed his practice as consulting geologist, after a summer spent in California.

MR. G. L. ELLIS is with the Trans-Continental Oil Company at Duncan, Oklahoma.

MR. E. O. MARKHAM, of the Carter Oil Company, recently returned from New York for field work in Oklahoma.

MR. S. P. BORDEN has resigned from the Gulf Production Company and has established an office as consulting geologist in Shreveport, Louisiana.

MR. L. D. DONNELLY is with the Maracaibo Oil Exploration Corporation, 43 Exchange Place, New York City.

MR. A. F. CRIDER is consulting geologist for the Dixie Oil Company in Shreveport, working under the direction of Mr. Sylvan S. Price, Chief Geologist for the Dixie Oil Company, First National Bank Building, Tulsa, Oklahoma.

MR. PIERCE LARKIN, Tulsa, Oklahoma, is consulting geologist for the Prairie Oil & Gas Company.

MR. HENRY HINDS is now chief geologist and vice-president of the Alcalde Oil Corporation, with headquarters at Tulsa.

MR. LEON RUSS who has headquarters at 25 Broadway, New York City, has recently been at Mexia, Texas.

MR. E. DEGOLYER made a brief trip to Mexico during January.

MR. C. L. ARNETT is geologist for the York State Oil Company at Caney, Kansas.

MR. ROBERT ANDERSON is now in California.

MR. LUCIAN H. WALKER is in charge of the field party exploring in China for the Standard Oil Company of New York.

MR. LLOYD E. WELLS is with the Arkansas Natural Gas Company on the Gulf Coast.

MR. G. L. ELLIS is chief geologist for Snowdon Bros., with headquarters in Fort Worth, Texas.

STACEY AND BURRESS completed their well in the SE¼ section 27 T. 18 N., R. 6 East, on the west side of the old Cushing Pool, Oklahoma, in the second break in the lime at a depth of 3,403 feet and have opened up a new pool which promises to be the forerunner of a number of pools in the second break around the edges of the old Cushing field.

MR. JOHN R. SUMAN, of the Rio Bravo Oil Company, has been in Tampico on a short trip.

MR. C. T. GRISWOLD is chief geologist for the Coline Oil Company in Oklahoma City.

MR. SAM W. WELLS AND MR. FORD BRADISH have established an office as consulting geologists in the Petroleum Building at Okmulgee, Oklahoma.

MR. E. W. SCUDDER is now geologist for the Gypsy Oil Company in Kansas, with headquarters at Winfield.

MR. GEORGE M. BEVIER is division geologist for the Atlantic Oil Producing Company in Houston, Texas.

The geologists of Denver and vicinity have organized the Rocky Mountain Association of Petroleum Geologists, with MAX BALL as President, J. M. DOUGLAS, Vice-president, and C. B. OSBORNE, Secretary-treasurer. There were seventeen members present at the first meeting and the report of the meeting states that thirty-one other geologists are members of the Association. Any geologist visiting Denver is asked to communicate with the secretary, Clarence B. Osborne, of the Midwest Refining Company, and they are invited to attend meetings of the organization while they are in Denver.

MR. EUGENE LILLY of St. Paul, Minn., is to sail February 4th for a tour of Egypt, Palestine and Europe, expecting to return early in the summer.

A recent statement in these columns to the effect that MR. E. L. ESTABROOK has the position of Chief Geologist for the Mid-West Refining Company is erroneous. MR. CARROLL H. WEGEMANN is Chief Geologist. Mr. Estabrook is engaged in special work for the company and has the title of Petroleum Production Engineer.

The firm of BAUER AND CLARK, consulting geologists, Okmulgee, Oklahoma, has been dissolved. Mr. C. Max Bauer, who was formerly with the U. S. Geological Survey, will have charge of geological work for the Mid Northern Oil Company, with headquarters at Billings, Montana. Mr. R. W. Clark will continue consulting work in Okmulgee.

DR. ED BLOESCH, who advises that his office is with Dr. O. Fischer, 721 Kennedy Bldg., Tulsa, has recently been in West Virginia.

MR. FREDERICK B. PLUMMER AND MR. RAYMOND C. MOORE are authors of a large report on the "Stratigraphy of the Pennsylvanian Formations of North-Central Texas," which has just been issued by the Bureau of Economic Geology and Technology, University of Texas. The report is accompanied by a large colored geological map of the Pennsylvanian area and detailed correlation charts.

Among members of the American Association of Petroleum Geologists who were present at the geological meetings in Amherst were Alan Bateman, J. W. Beede, E. Blackwelder, E. De Golyer, F. W. De Wolf, A. Ellisor, A. E. Fath, K. C. Heald, C. W. Honness, R. H. Johnson, J. F. Kemp, K. F. Mather, R. C. Moore, W. A. Nelson, S. Paige, C. Schuchert, G. O. Smith, David White and W. E. Wrather.

Mr. F. S. Prout is Consulting Geologist for the Douglass Oil Co., of Wichita, Kansas.

Mr. Richard Jones, of the Humble Oil & Refining Co., has been transferred from Ardmore to Mexia, Texas.

Mr. I. E. Dugan is in charge of exploratory drilling for the Marland Refining Co.

Mr. H. M. Robinson is working in east Texas.

Mr. W. E. Wrather will give a course of lectures during the Spring session of the University of Chicago on Petroleum Geology.

Mr. Jon A. Udden has lectured at the Rolla School of Mines, Rolla, Mo., on Subsurface Geology.

Mr. J. A. Oliphant is consulting geologist for C. B. Peters, Tulsa, Okla.

Mr. C. S. Ford is geologist for the Champlin Refining Co., of Enid, Okla.

Mr. Dorsey Hager, of Los Angeles, California, has recently issued a brochure of 31 pages entiled, "Oil Possibilites of the Holbrook Area in northeast Arizona."

The Tulsa Geological Society has elected the following officers for 1922: Luther H. White, President, Ed Bloesch, Vice President, Richard Hughes, Secretary, Frank C. Green, Treasurer; Harry F. Wright, R. S. McFarland and J. V. Howe, Councilors.

Mr. K. C. Heald represented the U. S. Geological Survey at the Osage sale, Dec. 12, 1921.

Mr. Dean E. Winchester, of the Standard Oil Co., of New Jersey, is in Brazil.

Mr. Harry F. Wright has moved from Wichita, Kan. to Tulsa, Okla.

Mr. J. Q. Myers of Fredonia, Kansas, is working in East Texas.

Mr. C. F. Bowen is in South America.

Mr. H. Harper McKee is in Venezuela.

The Twelfth Session of the International Geological Congress will be held in Belgium next summer.

Mr. A. D. Brokaw has been in Mexia in the interests of the Humphreys-Pure Oil interests.

Mr. George C. Matson has opened an office in Tulsa for the Schermerhorn Oil Co. Mr. C. W. Tomlinson is assistant to Mr. Schermerhorn in Ardmore, Okla.

Mr. O. B. Hopkins, Chief Geologist for the International Petroleum Co., Ltd., of Toronto, Canada, has left for the west coast of South America.

Mr. W. P. Haynes, with Mr. R. P. Walters as assistant, has gone to Europe for the Standard Oil Co., of New Jersey.

Mr. G. A. Elledge of the Atlantic-Cortez interests at Tampico has been in charge of drilling the first deep oil well ever completed with a diamond drill. The well is located in the Panuco field and was estimated as 1,000 barrels at 2,153 feet. The hole was drilled with a rotary drill to 1,400 feet where 4 inch casing was cemented. The remainder of the hole was drilled with a 3⅝-inch diamond bit which cuts a hole 3 13-16 inches in diameter. The "mudding" process was used in connection with the diamond drilling.

The Tulsa Section of the American Institute of Mining and Metallurgical Engineers elected the following officers for 1922: **Mr. H. B. Goodrich**, President, **Mr. J. A. Udden, Mr. W. E. Pratt and Mr. Sidney Powers**, Vice Presidents, **Mr. R. S. McFarland**, Secretary.

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